OCTOBER 1957

THE WELDING JOURNAL

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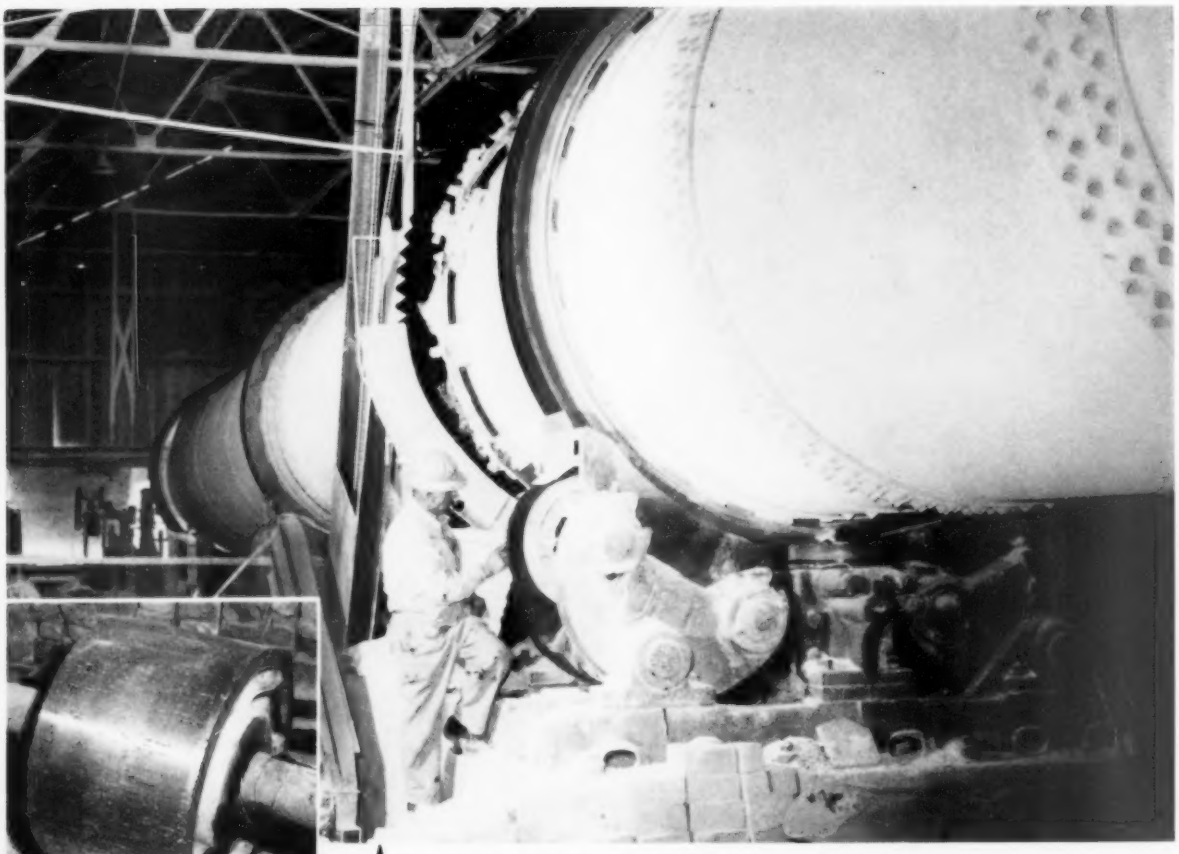

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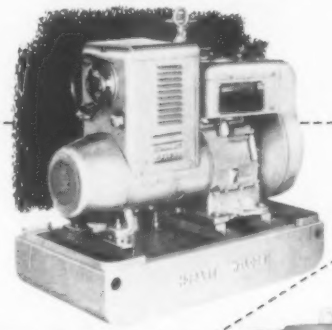

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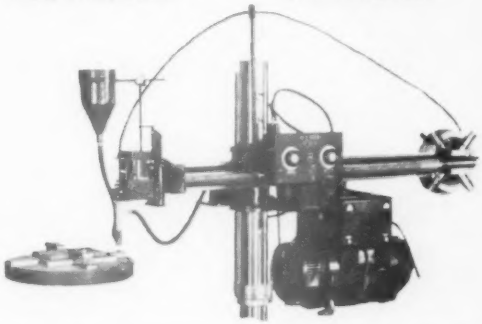

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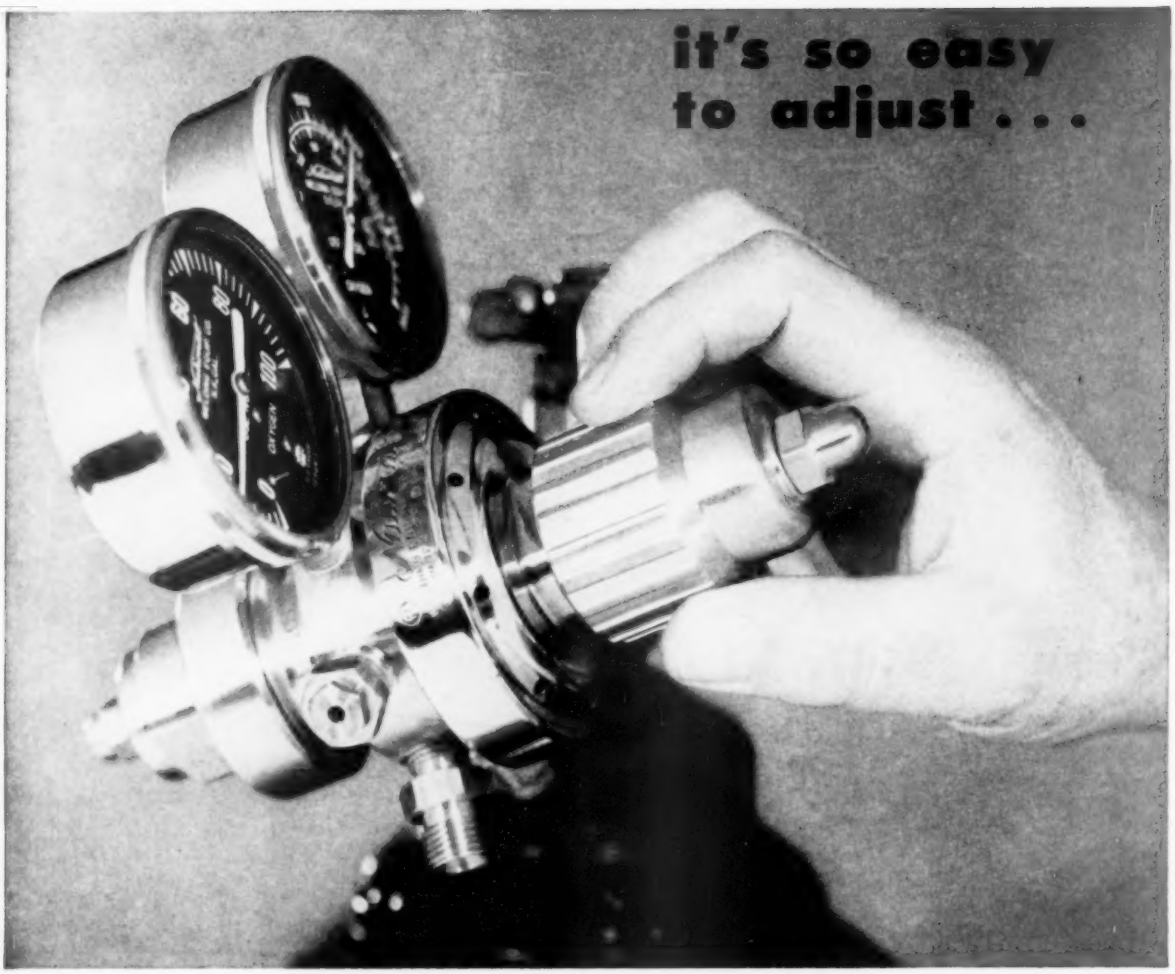

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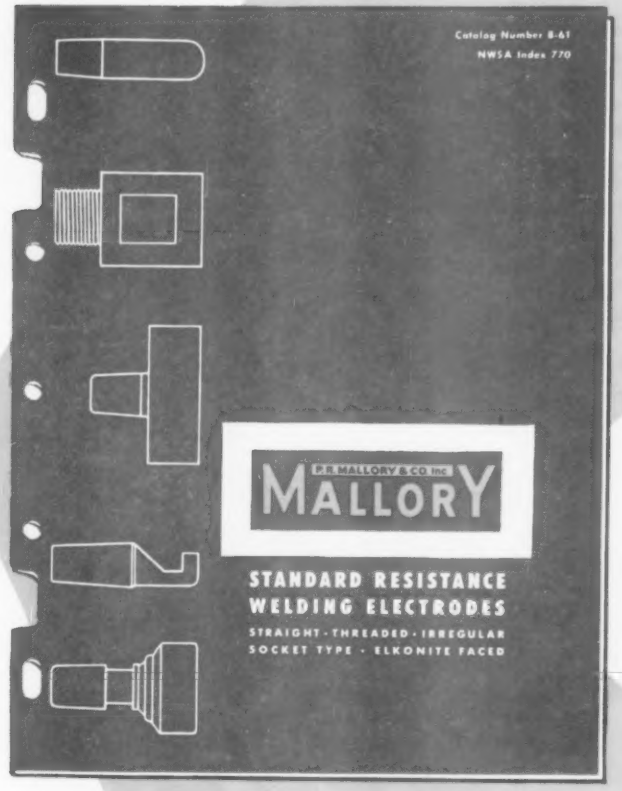

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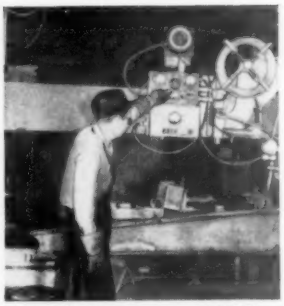

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Published for the advancement of the science and art of welding by the American Welding Society

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Subscriptions $7.00 per year in the United States and possessions; foreign countries $8.50. Single copies, nonmembers $1.00; members 75 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton, Pa., under the act of March 3, 1879.

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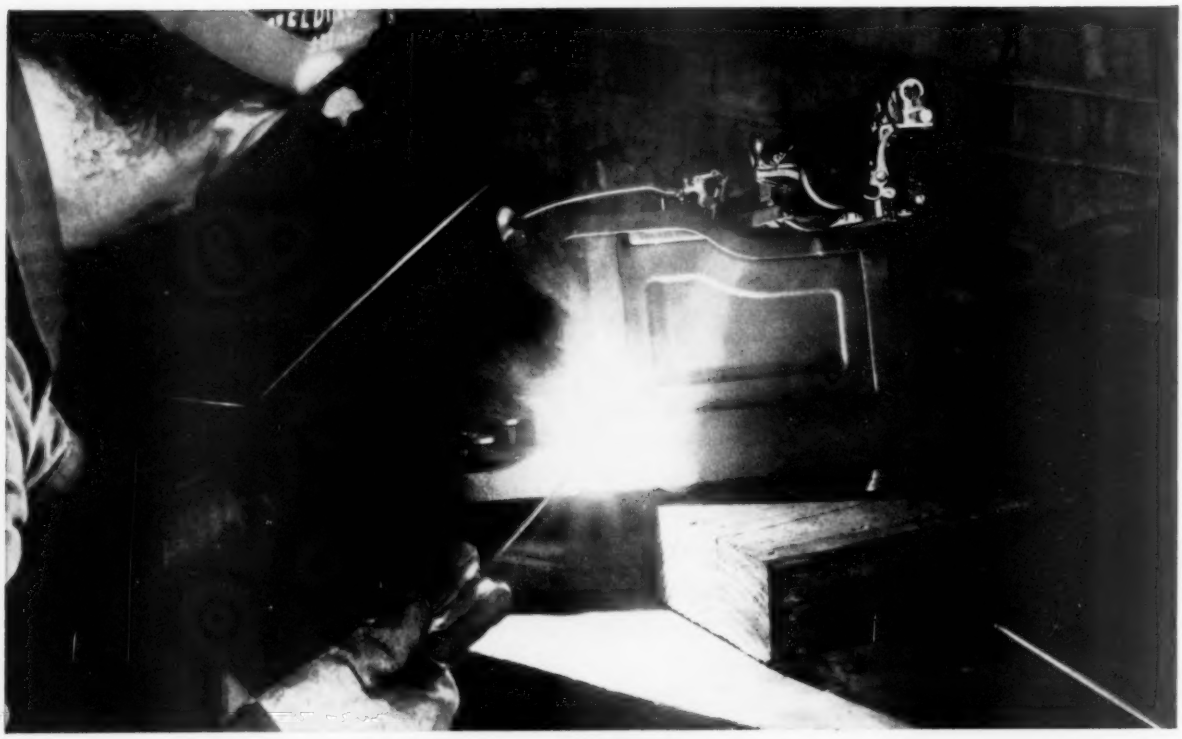

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MAKE THE SHOE FIT THE FOOT

Construction materials, welding procedures, design requirements and inspection standards should be adequate for anticipated service conditions, but they should be no more costly than these conditions warrant. This was the predominant theme of many of the papers and discussions presented early this year by guest speakers from industry at a Conference on Welding Engineering at Ft. Belvoir, Va.

Specification requirements for welded construction are often based upon information derived from laboratory tests. It is very important to evaluate the test results carefully by comparing the conditions of testing with those actually realized in service. Sometimes service conditions are difficult to determine with accuracy and they cannot be represented properly by the testing conditions. Therefore, results must be confirmed by correlation with experience before they can be accepted with full confidence.

Tests can be made to determine the fatigue resistance of a machine part, or a bridge member for given kinds of loading or stressing and numbers of repetitions of stress. If the results do not correlate with records of service behavior, the actual conditions of loading are probably different from those assumed in interpreting the testing data, or perhaps some unrecognized important variable was not controlled in the program of testing.

Impact tests involving quite severe rates of loading or straining and very unfavorable geometric constraint or stress raisers may indicate a structural steel material to be unsafe for operation below the so-called "nil ductility temperature" that is determined by such tests. However, wide-spread experience may have shown a long record of excellent behavior for some types of structures built of the same material, serving at minimum temperatures far below this "nil ductility temperature." This simply means that the testing conditions were not representative of the actual service conditions of these types of structures.

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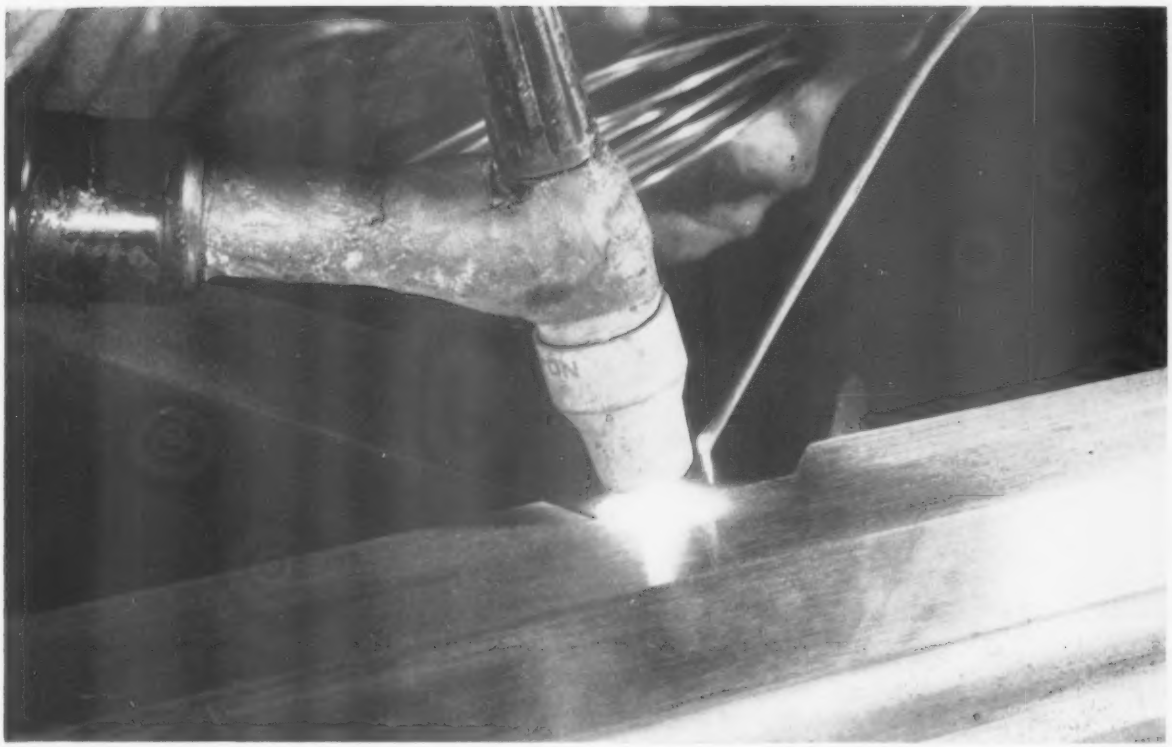

In gas-shielded welding the function of the gas is to exclude the surrounding air from the molten weld metal. The characteristics of the gas and its composition influence the effectiveness of the shielding and the stability of the arc

SHIELDING GASES FOR INERT-GAS WELDING

Paper reviews recent developments in inert-gas-shielded arc welding and provides up-to-date recommendations on the best-suited shielding gas for the inert-gas welding of all metals of commercial importance

BY W. H. HELMBRECHT AND G. W. OYLER

INTRODUCTION. The utilization of gas shielding is perhaps the oldest yet most adaptable means for preventing contact of the surrounding air with the molten weld metal during welding operations. Gas shielding in the oxyacetylene and oxyhydrogen processes is inherent and consists usually of a mixture of several such gaseous products of combustion as hydrogen, water vapor, carbon monoxide and carbon dioxide. Though these gases are chemically active at welding temperatures, the over-all effect of the shielding-gas mixture can be made oxidizing, neutral or reducing as desired by simple adjustment of the oxy-fuel gas ratio, thus permitting application of these processes to at least a limited variety of materials. In the covered-electrode metal-arc process, gas shielding is obtained by incorporating in the electrode-covering material certain organic constituents which at arc temperatures decompose to produce an atmosphere consisting mainly of carbon dioxide and carbon monoxide with or without a small amount of hydrogen. These gases, while primarily shielding media, contribute also to the stabilization of the arc and the general improvement of the arc characteristics.

These active shielding gases are most applicable to the welding of ferrous materials. However, their usefulness has been extended to some of the hard-to-weld materials such as aluminum and copper-base alloys through the use of suitable fluxes to form fusible metal oxide slags which do not interfere with the welding operation. Although inactive shielding gases such as argon and helium have long been considered ideal for virtually all materials, it was not until the postwar era when high-purity argon was produced economically on a commercial scale that inert-gas-shielded arc-welding processes became a practical reality. In recent years, processing and distribution methods have been perfected to furnish inert gases of ultra-high purity, and the tech-

W. H. Helmbrecht is Assistant Manager of Welding and **G. W. Oyler** is Division Head, Development Lab., Linde Co., Newark, N. J.

Presented at the 1956 AWS National Fall Meeting, Cleveland, Ohio, October 8–12.

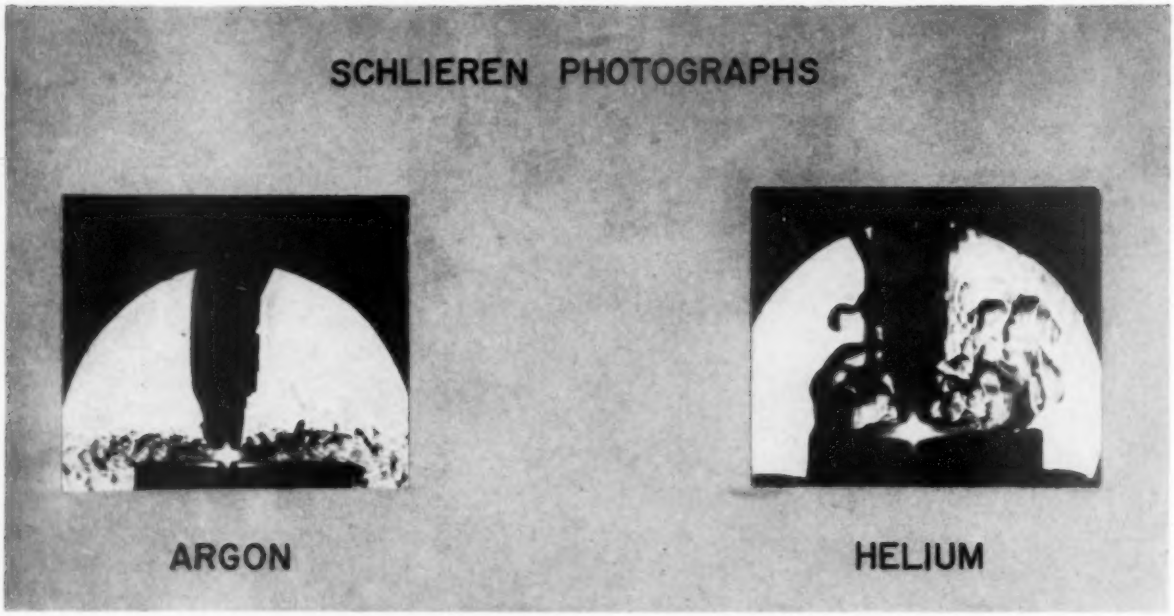

Fig. 1 Schlieren photograph showing shielding effectiveness of gas density

nology of the inert-gas welding processes has been significantly advanced.

It was natural in the early development of the inert-gas-shielded tungsten-arc process to utilize either of the two inert gases or mixtures of the two for all applications on all materials, since protection of the nonconsumable tungsten electrode was of prime importance. As more knowledge was gained with this process, and with the advent of the inert-gas-shielded consumable-electrode process, it became evident that the composition of the shielding gas could be "tailored" to specific applications by the addition of small amounts of active gases to argon or to helium. It is the purpose of this paper to review these developments and to provide as completely as possible up-to-date recommendations on the best-suited shielding gas for the inert-gas welding of all metals of commercial importance.

Characteristics of Gases

In order to more fully appreciate and understand the shielding gas recommendations in specific cases, consideration should be given to the characteristics of each inert gas, the dominant properties of the active gases, and the combined effect of each mixture on the molten weld metal. The primary function of the shielding gas is, of course, to exclude the surrounding air from the region of the molten weld metal. The characteristics of the gas influencing the effectiveness of the shielding are equally applicable to both processes. However, the composition of the shielding gas does determine the characteristics and behavior of the welding arc. Since the inert-gas-shielded consumable-electrode process is complicated by the transfer of metal from the electrode to the weld, it is necessary to consider each process separately.

The chief factor influencing shielding effectiveness is the gas density. Argon is approximately one and one-third times as heavy as air and ten times as heavy as helium. The significance of these densities relative to air is illustrated by the Schlieren photographs shown in Fig. 1. Argon, after leaving the torch nozzle, forms a blanket over the weld area, whereas the helium tends to rise in turbulent fashion around the nozzle. Experimental work has consistently shown that to produce equivalent shielding effectiveness, the flow of helium necessary falls in the range of two-to-three times that of argon. The same general relationship is true for mixtures of argon and helium, particularly those high in helium content; Fig. 2 shows the relationship of flow requirements to the cross-draft velocity for argon and for the 25% argon – 75% helium mixture using two different nozzle-to-work distances.

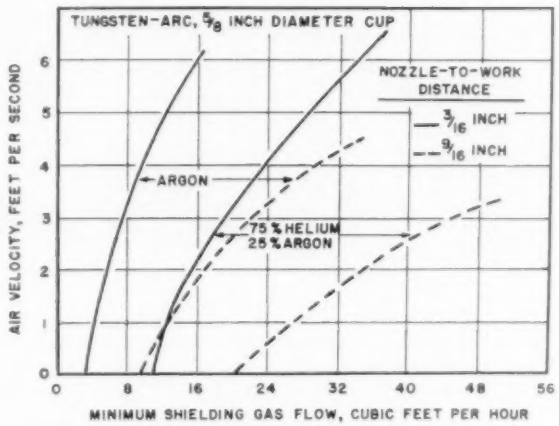

Fig. 2 Relationship of the flow requirements to the cross draft velocity

One important characteristic is the voltage-current relationships for argon and for helium in the tungsten-arc process such as are illustrated in Fig. 3. It is readily apparent that, for equivalent arc lengths and

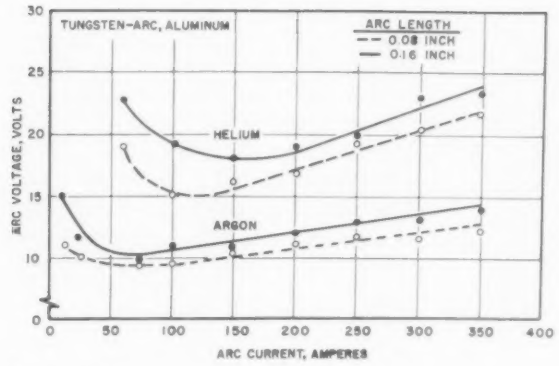

Fig. 3 Voltage-current relationship

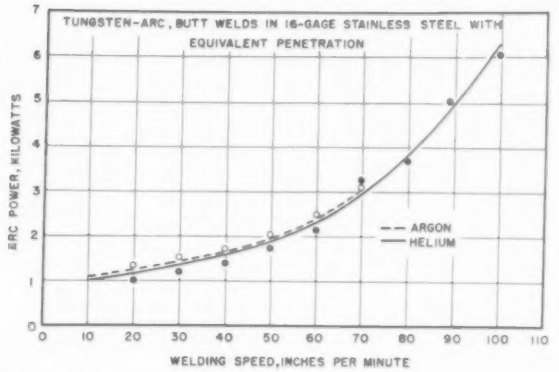
TUNGSTEN-ARC, BUTT WELDS IN 16-GAGE STAINLESS STEEL WITH EQUIVALENT PENETRATION
ARGON
HELIUM
ARC POWER, KILOWATTS
WELDING SPEED, INCHES PER MINUTE

Fig. 4 Effect of arc power on welding speed

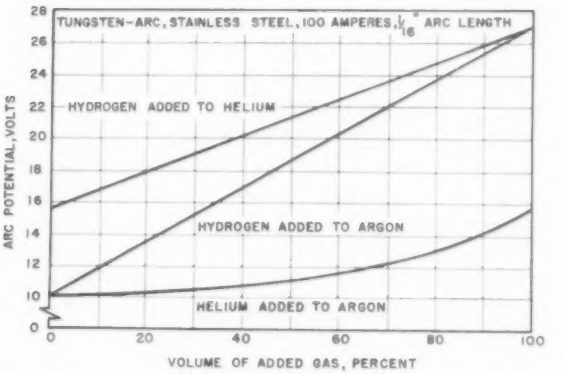
TUNGSTEN-ARC, STAINLESS STEEL, 100 AMPERES, 1/16" ARC LENGTH
HYDROGEN ADDED TO HELIUM
HYDROGEN ADDED TO ARGON
HELIUM ADDED TO ARGON
ARC POTENTIAL, VOLTS
VOLUME OF ADDED GAS, PERCENT

Fig. 5 Effect on arc potential of adding hydrogen to argon and to helium

welding currents, the voltage obtained with helium is appreciably higher than that with argon. Since heat in the arc is roughly measured by the product of current and voltage (arc power), the use of helium yields a much higher available heat than does argon. The higher available heat favors the use of helium over argon at the higher current levels which are used for the welding of the thicker materials, especially those having high thermal conductivity or relatively high melting temperatures. However, it can be noted that, as the current decreases, the curves pass through a minimum voltage at current levels approximately 90 amp apart and then the voltage increases as the current decreases. For helium this increase in voltage occurs in the range of 50 to 150 amp where much of the welding of thin materials is accomplished. Since the voltage increase for argon occurs below 50 amp, the use of argon in the 50- to 150-amp range provides the operator with more latitude in arc length to control the welding operation. Arc power is more than just a mathematical expression, as a study of Fig. 4 will show. Experimental work with argon and helium has demonstrated that, with equal arc power, good welds with equivalent penetration can be obtained at speeds up to 70 ipm. It is apparent that in order to obtain equal arc power, appreciably higher currents must be used with argon than with helium. Since undercutting with either gas will occur at about equal currents, helium will produce satisfactory welds at much higher speeds.

The other influential characteristic is that of arc stability. Both gases provide excellent stability with direct-current power. With alternating-current power, which is used almost exclusively on aluminum and magnesium, argon yields excellent arc stability and good cleaning action, whereas the use of helium results in poor arc stability and poor cleaning action. Thus with alternating current, argon finds wide acceptance over helium.

In the inert-gas-shielded tungsten-arc process, the choice of active gases which may be added is determined more by the tolerance of the electrode for the additive than by process considerations. Oxidizing gases cannot be used generally because of oxidation and resultant deterioration of the tungsten electrode. Oxygen additions as small as a fraction of 1% cause rapid loss of the electrode, and therefore have no practical usefulness. Additions of carbon dioxide to the shielding gas in amounts up to about 4 or 5% can be tolerated, but only extremely limited usefulness for this mixture has been found. Nitrogen can be added in very large amounts in so far as its compatibility with thoriated tungsten is concerned, but such mixtures have only very isolated application. In the small percentages that could be used on a few materials from a metallurgical viewpoint, it offers little, if any, benefit over the inert gases, singly or in combinations. Additions of hydrogen may be made to the inert gases or pure hydrogen may be employed since its chemical activity is one of a reducing nature and has no adverse effects on the tungsten electrode. Moreover, hydrogen possesses an extremely high arc-voltage characteristic which is effective in direct proportion to its content in the gas mixture. Figure 5 illustrates the effect on arc potential of adding hydrogen to argon and to helium. For purposes of comparison, the same relationship for additions of helium to argon is shown. From these curves, it is clearly evident that hydrogen is much more effective than helium as an additive to argon for producing higher voltages. The benefits obtained

from the addition of hydrogen to argon are twofold. First, the high arc voltage thus obtained yields high arc power at relatively low welding currents; and second, the hydrogen burns on exposure to the atmospheric air, thus providing an excellent shield at extremely low gas flows, generally about one-sixth that required with helium. Similar additions of hydrogen to helium will also produce useful increases in voltage, as shown in Fig. 5, but the increase is not nearly as great as with argon, and the improvement in welding performance is proportionately smaller. Moreover, the minimum flow requirements for the helium-hydrogen mixtures are still two to three times that required for the argon-hydrogen mixtures.

By virtue of the high voltage and low gas flows obtainable, argon-hydrogen mixtures, up to and including 35% hydrogen, are preferred to argon-helium mixtures in applications on stainless steel, nickel-copper alloys and nickel-base materials where the hydrogen does not cause adverse metallurgical effects. The arc voltage-length curves for argon, helium and various mixtures of argon and hydrogen are shown for comparison in Fig. 6. A 20% addition of hydrogen to argon produces arc voltages approximately equivalent to those of helium. Production experience has proved that these shielding gases will give equal performance.

The arc characteristics established by argon and by helium in the inert-gas-shielded consumable-electrode process are shown in Fig. 7. The voltage relationship for each gas using this process is much the same as it is for the inert-gas-shielded tungsten-arc process, but with smaller differences in voltage, percentagewise. However, the full advantage of the high voltage of helium can seldom be practically exploited because of the undesirable mode of metal transfer in helium. At all currents in the normal operating range, helium shielding produces globular metal transfer with all metals, resulting in high rates of spatter evolution and inferior weld appearance.

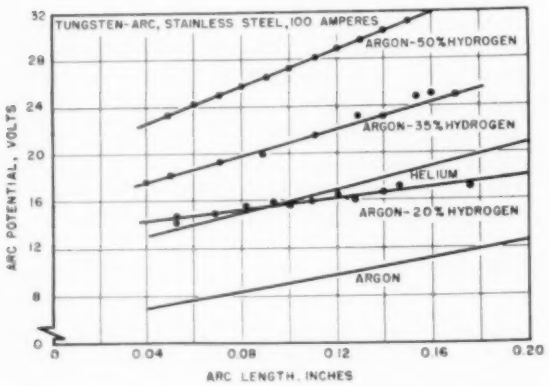

Fig. 6 Arc voltage-arc length curves for various gases

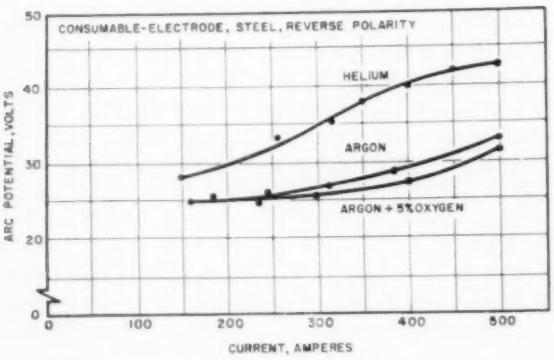

Fig. 7 Arc characteristics of various gases

Argon provides excellent arc characteristics on aluminum with no tendency for spatter evolution. With carbon and stainless steels, the addition of oxygen is necessary to produce a stable arc with spray-type metal transfer at relatively low currents.

Of the various active gases which are the most likely additives to argon or helium for inert-gas-shielded consumable-electrode welding, only oxygen additions to argon have proved to be beneficial. Even very small additions of oxygen to argon substantially improve the mechanism of metal transfer making possible the smooth, "spray-type" arc at currents considerably below those possible in pure argon. Increased additions of oxygen to argon provide no further improvement in the metal transfer, but additions up to about 5% do improve the coalescence of the weld metal with the base metal, and increase the speed at which undercutting occurs without producing adverse oxidation effects.

Additions of hydrogen or nitrogen do increase the arc voltage as might be expected but have adverse metallurgical and arc stability effects which make their use impractical. The addition of carbon dioxide to argon in various amounts has been explored with only a tendency for fringe benefits in isolated cases and certain attendant disadvantages.

The complete substitution of carbon dioxide for argon or helium has shown some technical and economic advantages in certain applications involving carbon steel but not without some compensating disadvantages. On this material the use of carbon dioxide is generally characterized by deep penetration, high evolution of spatter and inferior weld quality. On most, if not all other materials, carbon dioxide is not applicable.

Purity of Inert Gases

Argon and helium, though differing widely in physical properties and in origin, can be and are refined to about equivalent purity specifications. It has been possible in the last few years to obtain both gases in welding grades at a minimum purity of 99.99%; and at this level of purity, differences in the kind and relative amounts of impurities are not detectable in the welding operation. Although some metals like carbon steel and copper apparently have a high tolerance for relatively large amounts of contaminants, others such as aluminum and magnesium are sensitive to impurities. Still others such as titanium and zirconium

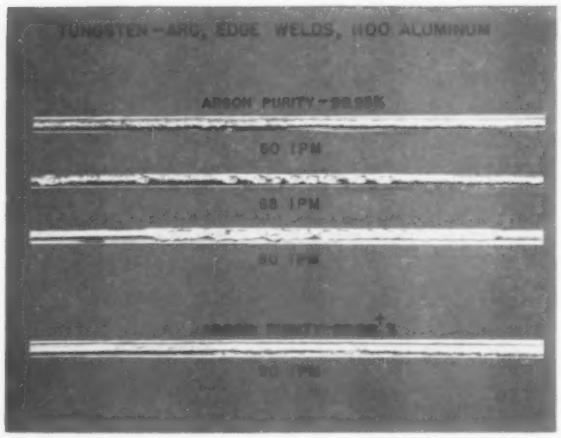

Fig. 8 Effect of gas purity on welding performance

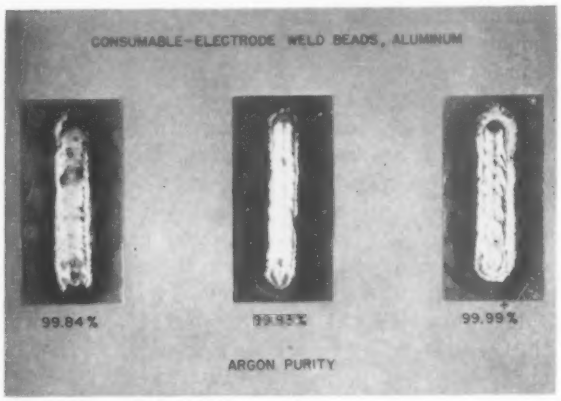

Fig. 9 Effect of gas purity on the degree of cleaning action obtained

have extremely low tolerances for any foreign constituent in the inert gases. The effect of gas purity on welding performance with the tungsten-arc process using argon as the shielding gas is illustrated in Fig. 8. The upper three edge welds in the photograph were made using argon having a purity of 99.93% and the bottom edge weld was made with 99.99+% argon. With the lower purity gas, good results were obtained at 60 ipm, but as the speed was increased to 68 and 80 ipm, lack of coalescence became more and more pronounced as shown. However, the use of the higher purity gas produced excellent results even at 90 ipm. Somewhat the same kind of differences can be shown using the consumable-electrode process. Figure 9 shows, in order from left to right, three bead-on-plate welds in aluminum made using argon from three sources and having purities of 99.84, 99.93 and 99.99+%. The weld at the left of the photograph illustrates a complete lack of cleaning action at the leading edge of the weld crater as well as a heavy black deposit along both sides of the weld bead. The weld in the middle of the photograph shows improved cleaning action at the front of the weld crater and along both sides of the weld bead and a somewhat less dense "sooty" deposit. The weld at the right shows a broad band of cleaning action completely around the weld, and the least amount of the black deposit. The amount of this cleaning action at the leading edge of the weld puddle is important since it determines the maximum speed of progression and to some degree the weld quality. For these reasons, every precaution must be taken to prevent contamination of these highly purified shielding gases by atmospheric air during their handling, distribution and ultimate use.

Argon is obtained from the atmosphere by the liquefaction of air, refined and transported as a liquid at temperatures below approximately −300° F. Depending upon the customer's rate of usage, argon may be supplied as a liquid and stored as a liquid on his premises, supplied as a liquid and stored as a compressed gas, or supplied as a compressed gas in cylinders.

At the temperature of liquid argon, moisture does not exist and there is no likelihood it can be introduced during reconversion of the liquid to the gaseous state. "Moisture in the gas" is a more-than-occasional target of complaints arising from unsatisfactory welding operations, and the complaint may be occasionally substantiated by on-the-spot dew-point measurements. Extensive experience has shown, however, that dew-point measurements in the range concerned are difficult to obtain accurately even with laboratory-type equipment. In using dew-point measuring devices, there is a general tendency to employ rubber tubing extensively. This practice makes the "reading" of doubtful value since rubber tubing transmits moisture readily. Moreover many dew-point devices require visual detection of moisture on a cold polished surface, thus providing an area where the judgment of the observer is an important factor.

Contamination of argon with moisture and atmospheric gases, if it occurs, is most likely to be caused by defects in piping systems, the wide use of flexible conduits which have high transmission rates for moisture, or failure to observe all recommended operating procedures.

In contrast to argon, helium is obtained from underground wells, purified and distributed in gaseous form since it cannot be liquefied practically on a commercial scale. In most other ways, the handling methods for helium are about the same as those for argon and the comments on contamination covered above for argon apply equally to helium.

Welding

The final selection of the "best" shielding gas must be the result of considering and weighing such factors as the type and thickness of material, joint design and fixturing, process employed, economics and the speed and quality requirements. Recommendations in a limited discussion must necessarily cover only the categories having the most significant bearing on the choice of the shielding gas. The following general recommendations are made primarily on the basis of

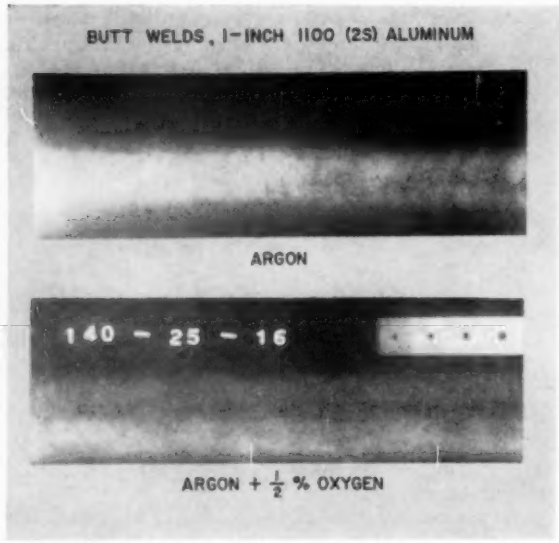

Fig. 10 Effect on aluminum weld soundness of adding oxygen to argon

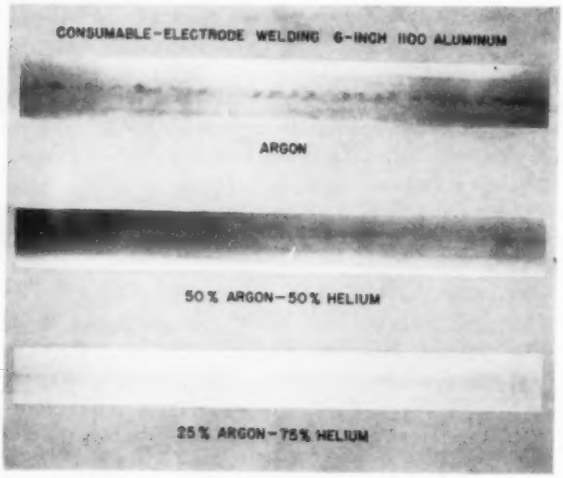

Fig. 11 Gas preference for welding heavy aluminum

metal and process but consider also the influence of material thickness and the differences between manual and mechanized welding.

Aluminum

In the manual tungsten-arc welding of aluminum, argon employed with alternating-current power and high-frequency stabilization is superior to helium as the shielding gas. The use of argon provides better arc starting, better cleaning action and superior weld quality in production work than does helium. The lower total arc voltage employing argon is advantageous in manual welding since the operator has a greater flexibility of arc length without appreciably changing the power, thus affording greater ease of manipulation. Higher welding speeds can be obtained using helium with direct-current, straight-polarity (DCSP) power, but much more skill is required to produce satisfactory welds. When this combination is used, porosity frequently develops at the base of the joint due to insufficient cleaning action and poor control of the penetration unless deep-grooved backing bars are employed.

In mechanized welding, the arc length is essentially constant and thus variation in heat input is not a controlling factor as it is in manual welding. For a high-speed type application, such as tube welding, helium with DCSP can be employed; however, the weld quality may be poorer than when argon is used because of the absence of cleaning action. The cost of using helium is somewhat greater since its flow rate must be necessarily higher than that of argon to have adequate shielding. Argon-helium mixtures can be employed where a compromise between speed and quality is satisfactory.

In the inert-gas consumable-electrode welding of aluminum, argon is preferred for applications which employ plate up to 1 in. in thickness. Better metal transfer, arc stability and consequently much less spatter are obtained using argon than when employing helium. In the position-welding of 1100 and 3003 aluminum, it has been found advantageous to add a small amount of oxygen to the argon to improve the coalescence. Also, as can be noted in Fig. 10, the addition of ½% oxygen to argon produces welds which are superior in soundness to those obtained with argon in 1-in. thick 1100 aluminum.

For the welding of plates between 1 and 2 in. in thickness, a choice in gases between argon and a 50% argon – 50% helium mixture can be made depending upon the particular type of application. In this range of thickness, it is desirable to have the high heat input associated with helium and the excellent cleaning action obtained with argon. Table 1 shows the recommended preferred gases for the various thicknesses of aluminum. For the welding of 2- to 3-in. thick material, a choice between the 50% argon – 50% helium and the 25% argon – 75% helium mixtures can be made depending on each individual case. However, for the welding of materials thicker than 3 in. such as is employed for busbars and nuclear power vessels, it is recommended that the 25% argon – 75% helium mixture be used. For such heavy sections, a high heat-input type of gas must be used to minimize the formation of porosity. In Fig. 11, the superiority of the 25% argon – 75% helium mixture is clearly evident

Table 1—Shielding Gas Preference—Aluminum, Consumable-Electrode

Plate thickness, in.	*Gas mixture*
0–1	Argon
1–2	Argon 50% argon – 50% helium
2–3	50% argon – 50% helium 25% argon – 75% helium
3+	25% argon – 75% helium

for the welding of 6-in. thick 1100 aluminum. The use of 100% helium is not recommended for any thickness since poor arc stability and the inherently greater amount of spatter that is evolved are undesirable for any application.

Mild Steel

Manual inert-gas-shielded tungsten-arc welding is employed primarily on material up to $^1/_8$ in. thick. In applications in which this process is employed, high-quality, good-appearing welds are required. Therefore, to provide the operator with the greatest ease of manipulation and freedom from overheating the molten metal, argon is used exclusively. In the welding of thicker materials, the inert-gas-shielded consumable-electrode process is usually employed; however, there are occasions in which the tungsten-arc process must be used. In such cases either argon or argon-helium mixtures can be employed depending on joint preparation. For manual or mechanized spot welding of steel, argon is superior to helium or argon-helium mixtures because of much greater electrode life, better weld-nugget contour, ease of starting and lower shielding-gas cost.

For the tungsten-arc welding of pipe, argon is recommended as the shielding and backing gas. Since the quality and contour of these welds depend largely on the operator's skill, argon is preferred over helium because the puddle is much easier to control. The backing gas and shielding gas should be the same to avoid uncontrollable alterations of the shielding gas characteristic in the many places where the backing gas leaks through the unwelded joint. When using argon, the inside bead is more uniform and the penetration is easily controlled in all positions.

Argon is recommended for the mechanized welding of steel up to a thickness of 14 gage. If the tungsten-arc process is used in preference to the consumable-electrode process for welding thicker sheets, then the addition of helium is recommended to provide the necessary penetration.

The tungsten-arc process is employed in spot welding and stator-pack welding application. Argon is preferred over helium and argon-helium mixtures because it provides much lower gas costs, better arc starting and increased electrode life. In stator-pack welding, the use of argon also produces a clean weld whereas the use of helium causes a deposit of soot which must be removed later. Equal welding speeds are obtained with both gases since the maximum speed is limited by the geometry of the stator and the operation of the welding machine rather than by process characteristics.

In the inert-gas-shielded consumable-electrode welding of carbon steel, argon, helium or argon-helium mixtures are not recommended. The use of argon containing 5% oxygen is recommended. Several benefits are derived from adding oxygen to the argon. The mechanism of metal transfer is altered so that there is a tremendous improvement in drop rate and arc stability. The transition current for spray-type metal transfer is lowered, thus permitting the use of a lower-cost, larger diameter wire on a given application. It also permits welding of thinner materials using a given wire size. The use of oxygen in the shielding gas produces a more fluid and controllable weld puddle with good coalescence and bead contour. The tendency for undercutting is minimized, permitting welding speeds to be increased. The welds made using argon – 5% oxygen as compared to those made with any other shielding gas have less porosity, are wider, flatter and better faired into the base metal-resulting in a reinforcement of a more desirable shape. The argon – 5% oxygen mixture can be employed with either direct current, reverse polarity (DCRP) or DCSP giving comparable welding results.

Carbon dioxide may also be employed as the shielding gas in mechanized operations. The radiographic quality of a weld made in a typical high-speed welding application using a silicon-deoxidized wire and carbon dioxide is shown in the upper portion of Fig. 12. The lower radiograph shows the sound weld which can be made using a specially deoxidized wire. It is evident that a large amount of spatter is present in both cases. A typical cost comparison is shown in Table 2 for manual fillet welds made in steel using argon – 5% oxygen with reverse and straight polarity, and using carbon dioxide with reverse polarity. The deposition rate using argon – 5% oxygen especially on straight polarity is much higher than that of carbon dioxide; thus the arc time per 100 ft of weld is much less. In calculating the total cost of consumable materials, labor and overhead, the welds can be made at lower total cost using argon – 5% oxygen with DCSP. In addition, the quality of the welds in regard to spatter and porosity is superior using argon – 5% oxygen than with carbon dioxide.

Using very small diameter wires such as $^1/_{32}$ in., argon – 5% oxygen is superior to carbon dioxide in the welding of thin materials since the high voltage and

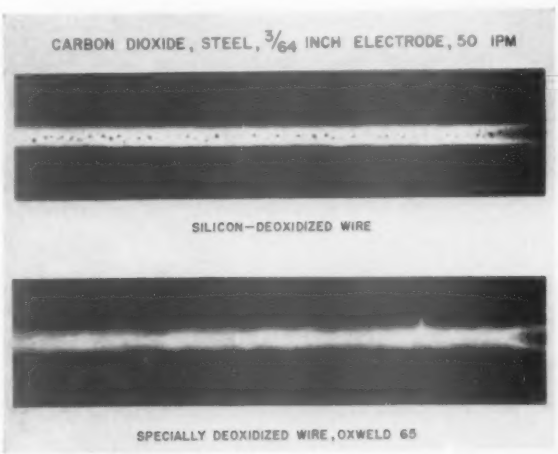

Fig. 12 Comparison of radiographic quality using two types of filler wires

Table 2—Typical Cost Comparison of Manual Consumable-Electrode Fillet Welds in Steel

	Argon – 5% Oxygen				CO_2, DCRP	
	DCRP		DCSP			
Operating data:						
Travel speed, ipm	12	18	16	23	10	16
Welding current, amps	270	400	320	400	250	330*
Deposition rate, lbs/hr	8.8	14.5	14.4	18.0	8.0	11.4
ARC time, hrs/100 ft	1.67	1.10	1.25	0.87	2.00	1.25
Cost data:						
Welding wire ($0.35/lb)	5.43	5.92	6.30	5.49	5.60	5.00
Gas (argon, $0.10/cu ft, CO_2, $0.01/cu ft)	6.68	4.40	5.00	3.48	0.80	0.50
Labor and overhead ($5.00/hr, 50% operating factor)	16.70	11.00	12.50	8.69	20.00	12.50
Total Cost, $/100 ft of weld	28.81	21.32	23.80	17.66	26.40	18.00

* Limit of current for good quality welds, except on killed steels.

consequently the high heat input obtained with carbon dioxide causes excessive penetration.

Stainless Steel and High-Temperature Alloys

For stainless steel and high-temperature alloys, argon is recommended for the manual tungsten-arc welding of a wide range of thicknesses in all positions. This choice is based primarily upon the need for puddle control, especially in position welding.

In mechanized welding, the weld puddle control effect is minimized and the penetration and welding speed factors are of great importance. In a great many production applications such as those found in fabrication of jet engines, food equipment and chemical apparatus, argon, argon-helium mixtures, argon-hydrogen mixtures or helium may be used. Argon is generally preferred for welding materials up to about 14 gage where the maximum possible speed is not required. On the heavier materials, especially where top speed is more important, argon-helium mixtures are preferred. In continuous welding operations such as tube welding where welding speed and bead contour are paramount, helium or an argon-hydrogen mixture is recommended.

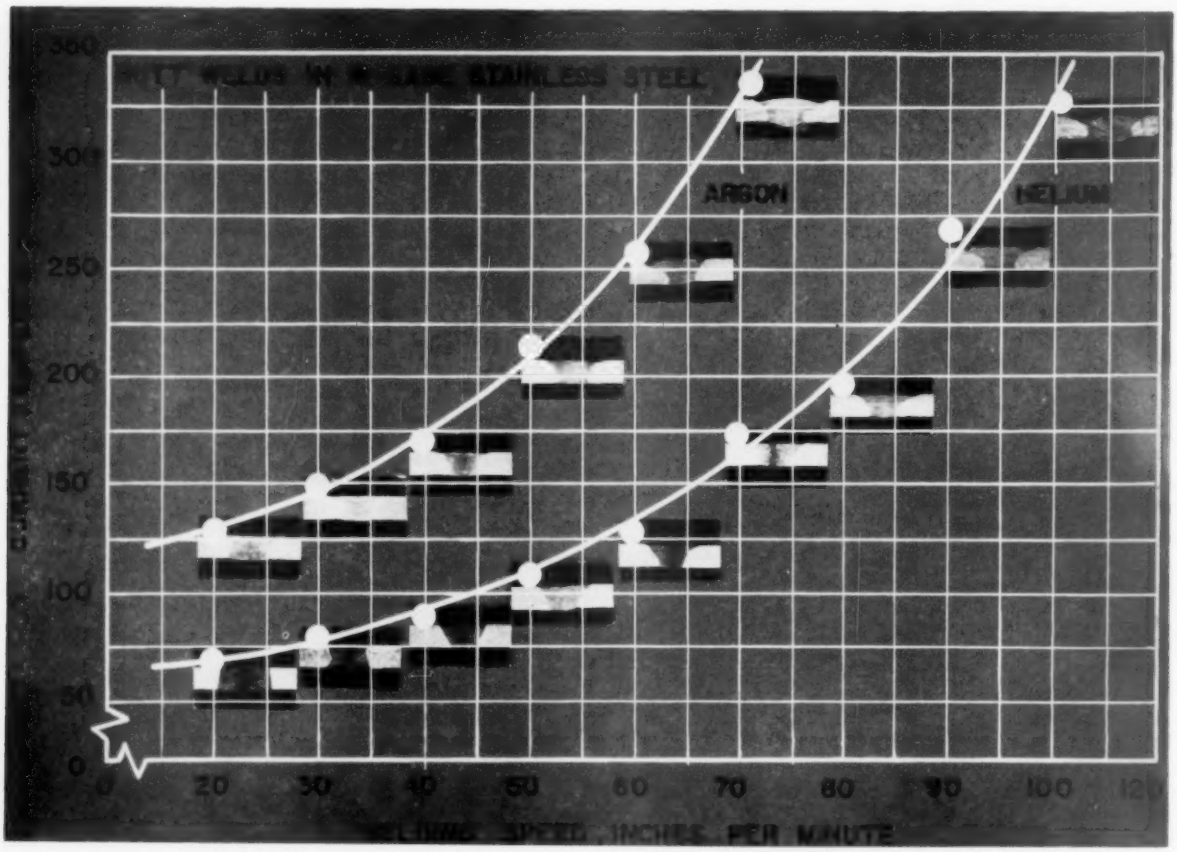

Fig. 13 Cross-sectional and graphical study of butt welds made in 16-gage stainless steel

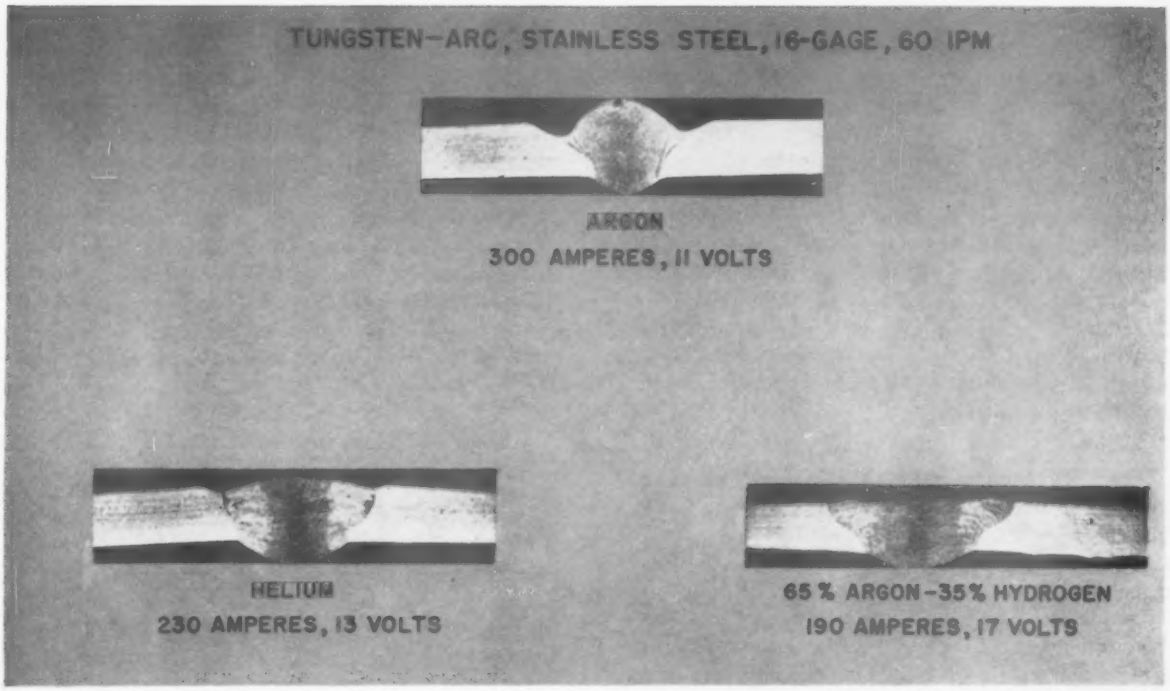

Fig. 14 Cross sections of tube welds made using various gases

Figure 13 shows a cross-sectional and graphical study of butt welds made in 16-gage stainless steel and illustrates the pronounced increase in speed that can be obtained at equal currents using helium as compared to argon. For example, at 150 amp the speed employing helium is twice that with argon. The increased arc voltage obtained with helium provides a higher input power at equal current levels, thus permitting higher welding speeds without obtaining undercutting.

The alternate choice for mechanized welding is the argon-hydrogen mixtures in which the hydrogen content may vary between 5 and 35% depending on the type of joint and technique employed. In Fig. 14, the cross sections of three tube welds are shown using argon, helium and argon–35% hydrogen as the shielding gases. Using essentially equal power at a constant welding speed, undercutting was obtained with both argon and helium, whereas no undercutting was noted for the argon-hydrogen mixture. This is primarily the result of the exceptionally high arc voltage obtained with this mixture, thus producing a very desirable weld contour at the low current level. In addition, very low flow rates can be employed when using argon-hydrogen mixtures since the hydrogen burns upon contact with the air, thus giving an added shielding envelope not obtained with the other gases. Adequate shielding has been obtained using flows in the order of 10 cfh when flows of 50 cfh of helium would be required. Some "know-how" and experience are necessary to employ the proper mixture of argon and hydrogen along with the proper technique to avoid the formation of porosity and still obtain the advantages of higher speeds and lower gas consumption.

In the inert-gas consumable-electrode welding of stainless steel, argon with 1% oxygen is generally recommended. The oxygen additions whether they be 1% or 5% provide the same benefits as are derived in the welding of carbon steel. In addition to the improved metal transfer, increased droplet rate, lower transition point and better arc stability, the oxygen also provides an even greater improvement in coalescence than is noted in the welding of steel. In many applications, especially at high speeds, it is impossible to make a weld with argon because of poor coalescence; however, with the addition of even 1% oxygen, excellent contour welds fairing smoothly into the base plate can be produced. Therefore, argon, helium or argon-helium mixtures are not recommended since they all give poor coalescence, as well as poor arc characteristics and spatter, without the addition of oxygen.

Argon with 5% oxygen is recommended in those applications, especially under $^{3}/_{16}$ in. where the argon with 1% oxygen does not give the desired arc stability, coalescence or welding speed. The use of 5% oxygen will result in slight but harmless discoloration or oxidation of the weld-metal surface.

Microexamination of welds made using argon with 5% oxygen show them to be sound and free of inclusions. The tensile, yield, elongation and impact properties are satisfactory. Accelerated corrosion tests in boiling 65% nitric acid were made on several grades of stainless. Table 3 presents the corrosion data for Type 347 welded with either 347 or 321 electrodes. The corrosion rate of the weld metal using either $2^{1}/_{2}$

or 5% oxygen in argon was much lower than that of the weld made with pure argon. For example, the rate of corrosion of the weld in 347 plate welded with the 347 wire given in the top line was 0.00102 in. of penetration per month, whereas the one made using argon with 2½% oxygen was 0.00079. The corrosion rate of welds made using atmospheres containing oxygen is in the same order of magnitude as that of the base plate.

Chemical analysis was taken of the weld made in Type 347 plate with 347 wire used in the corrosion tests. The data are tabulated in Table 4 and substantiate the corrosion data in that little or no alloy loss was noted for any of the elements present. Especially notable is the good recovery of chromium, nickel and columbium.

Copper, Nickel and Their Alloys

Argon is recommended for the manual tungsten-arc welding of copper, nickel and copper-nickel alloys. Argon-helium mixtures have some advantage in the welding of the heavier thicknesses. In comparing argon with other gases, less operator skill is required to control the fluid puddle for the purpose of obtaining the desired penetration and bead smoothness. Helium is recommended for welding heavy sections because the increased voltage provides a hotter arc for welding these high-melting point, high-conductivity metals. Argon can be employed if auxiliary preheat is used.

In mechanized operations, argon is preferred for welding these materials up to the thickness of about 1/16 in. For all applications involving greater thicknesses of nickel or copper, helium or an argon-helium mixture is recommended.

In the mechanized inert-gas-shielded consumable-electrode welding of copper, nickel and their alloys, argon is preferred for welding material up to 1/8 in. in thickness. For the welding of thicker plate, an argon-helium mixture is preferred. The amount of helium in this mixture varies between 50 and 75% depending on the type of joint and thickness of material employed. Table 5 illustrates the optimum shielding gases in the order of their preference for two thicknesses of nickel, Monel and Inconel alloys. In the case of welding Monel and Inconel alloys in the 1/4-in. double-vee joint, a choice can be made between pure argon and the 50% argon – 50% helium mixture since the penetrating characteristic of helium is not as essential in a beveled joint as in a square butt joint. In any event, helium should not be used for consumable-electrode welding of these metals because of the inherent arc instability and evolution of spatter.

Magnesium

In the tungsten-arc welding of magnesium, argon is preferred because of the excellent cleaning action obtained, ease of puddle manipulation in manual welding and the low gas flows that are possible. Alternating-current, high-frequency (ACHF) power is generally used in combination with argon to provide the required cleaning action and deep penetration. Helium can be used with DCRP power at very low currents to weld materials thinner than 1/16 in. but it is not recommended because of the high level of operator skill that is required. In general, tungsten-arc welding is superior to consumable-electrode welding since higher speed and better quality welds can be made at lower cost in magnesium.

The arc characteristics of helium and argon are somewhat different in the consumable-electrode welding of magnesium than they are with other metals. The burnoff rates of the wires are equal for both gases at equal currents, and the penetration is greater with argon-helium mixtures. Thus, argon is recommended in most cases because of the excellent cleaning action obtained. The argon-helium mixtures might be pre-

Table 3—Corrosion Data for Consumable-Electrode Welds in Stainless Steel

		Corrosion rates*			
			Weld metal		
Base plate	Welding wire	Base plate	Argon	Argon + 2½% O_2	Argon + 5% O_2
347	347	0.00078	0.00102	0.00079	0.00083
347	321	0.00078	0.00169	0.00115	0.00115
321	321	0.00143	0.00182	0.00172	0.00157

* Inches of penetration per month.

Table 5—Recommended Shielding Gases for Consumable-Electrode Welding

	1/8 in. butt		1/4 in. double vee	
Material	Preference	Gas mixture	Preference	Gas mixture
Nickel		75% helium		50% helium
	1	25% argon	1	50% argon
		50% helium		75% helium
	2	50% argon	1	25% argon
	3	Argon	2	Argon
Monel and Inconel alloys		50% helium		50% helium
	1	50% argon	1	50% argon
	2	Argon	1	Argon

Table 4—Chemical Composition—Consumable-Electrode Welds, Stainless Steel

	Analyses, %					
Sample	C	Mn	Si	Cr	Ni	Cb
347 Plate	0.044	1.50	0.54	18.14	10.07	0.50
347 Wire	0.044	1.56	0.42	18.19	9.07	0.67
Weld—argon	0.048	1.42	0.46	17.79	9.55	0.64
Weld—2½% O_2	0.040	1.41	0.48	17.86	9.43	0.63
Weld—5% O_2	0.042	1.36	0.43	17.89	9.38	0.62

ferred in multipass welding where the rounded type of penetration pattern is more desirable. Helium is not recommended because of the poor arc stability and great spatter evolution.

Titanium

In the manual tungsten-arc welding of titanium thinner than 1/8 in., argon or helium can be employed as the shielding gas, but argon always provides the lowest cost. Low flows of argon, such as 15 cfh, and helium flows in the order of 40 cfh are sufficient even when employing the recommended large diameter shielding cups. High flow rates cause turbulence in the gas pattern and consequently contamination of the weld. Good chill from the backing bar and the hold-down presses must be employed in conjunction with the shielding to prevent embrittlement. It is preferred to use a grooved backing bar with inert-gas backing to prevent air from contaminating the underside of the weld. For the manual welding of thicker plate, helium is recommended to obtain the desired penetration. Very little welding has been done outside of a chamber on the heavy thicknesses; however, if it is necessary, a trailing shield should be used.

In the mechanized welding, the same chill conditions, backing gas and flow of gases through the shielding cup must be used as was the case in manual operation. In addition, a trailing gas shield must be employed to prevent the contamination of the weld since normally a higher speed is employed in mechanical operation. The gas flows in the shielding cup and the trailing shield should be controlled independently.

A great amount of difficulty has been encountered in the consumable-electrode welding of titanium as arc instability and air contamination have been the major problems. From experience on other metals, helium could not be used as it would add to the instability. Therefore, most probably argon or some argon-low content helium mixture would be the recommended gas.

Experimental Gas Combinations

Experimental work has been done on several ternary mixtures of argon, helium and oxygen. These mixtures have been effectively used in the inert-gas-shielded consumable-electrode process for the welding of steel and stainless steel. There has been no active promotion of these mixtures because of the supply and mixing problems.

Various argon-carbon dioxide mixtures have been investigated for consumable-electrode welding, but there is no technical or economic advantage to adding less than 15% carbon dioxide. At this addition, the undesirable characteristics of carbon dioxide (arc instability and spatter) have already dominated. Double gas cups have been investigated for the tungsten-arc welding of aluminum and stainless steel, with argon gas being used in the inner cup and carbon dioxide in the outer cup. In some cases, good results have been obtained but it generally is in those instances where excessive argon flows have previously been employed. The use of carbon dioxide in the outer cup does tend to offer some resistance to drafts when abnormal air currents are encountered.

It has been reported that argon-nitrogen mixtures are suitable for tungsten-arc welding of steel. However, even though this information was announced generally several years ago, it has not been used in production since difficulty with porosity is generally encountered when nitrogen comes in contact with molten steel. It has also been reported that argon-hydrogen mixtures can be used on steels. Additions in the neighborhood of 10% have been used on killed steel for both tungsten-arc and consumable-electrode welding.

Very recently, a mixture of argon and 0.3% chlorine has been employed for the consumable-electrode welding of aluminum. Little information is available as to its relative merits.

Summary

Since the advent of welding, shielding gases produced from fluxes or coatings or added externally have been employed to protect the molten weld metal from air contamination. The discussion of shielding gases in this paper has included the inert gases as well as the addition of active gases to argon primarily. The arc characteristics, flow rate and weld quality obtained with each gas or gas mixture have been summarized for each metal and for each inert-gas process whether used with manual or mechanized operation. Argon has proved to be universally the best shielding gas. Argon-base mixtures with additives have been useful in tailoring the shielding gas to the requirements of specific metals and applications. The operator or welding engineer should be able to make the proper choice of the desired composition of his shielding gas for each application from the general information presented.

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ELECTRICAL REQUIREMENTS FOR AUTOMATION

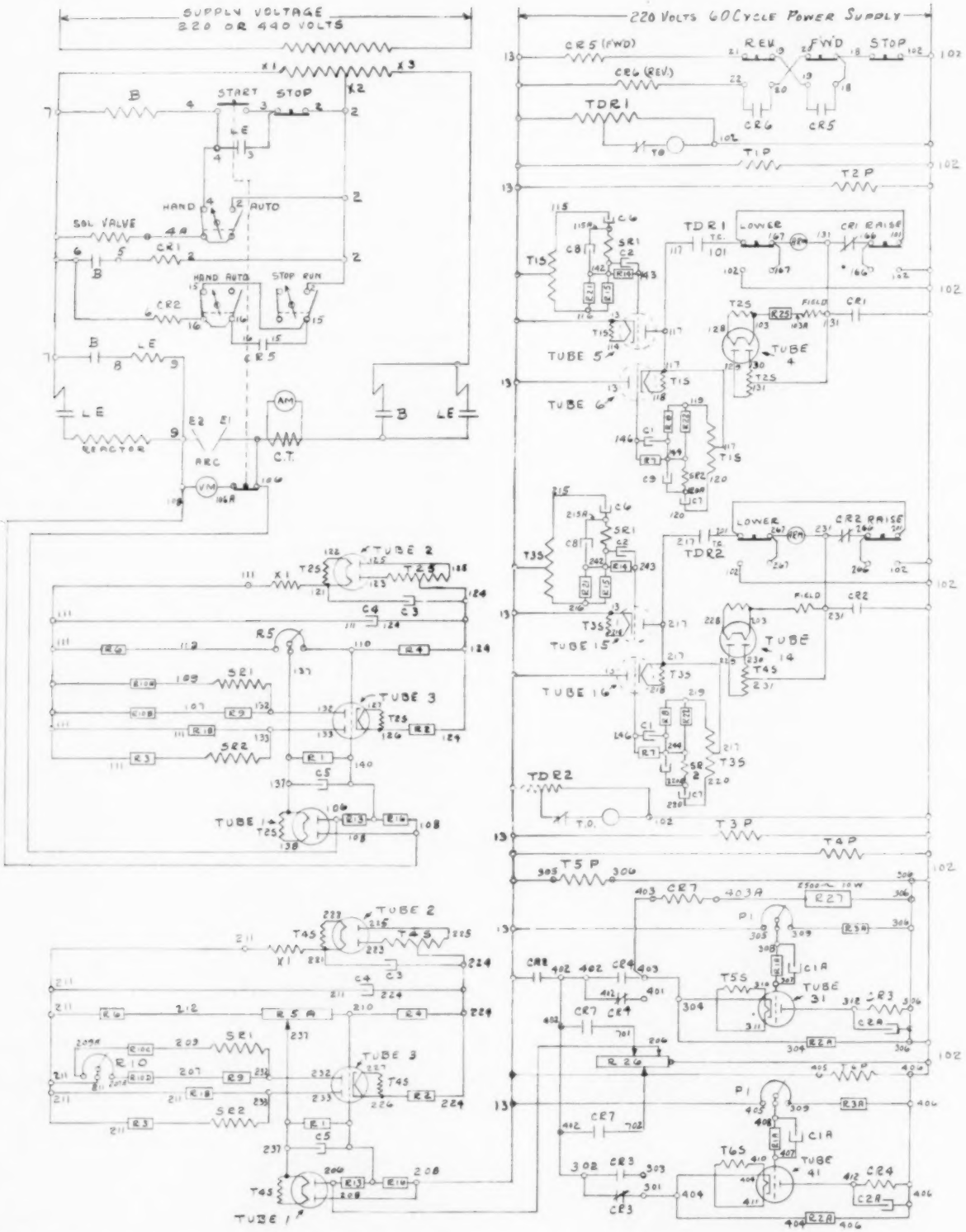

Fig. 1 Circuit of arc-voltage-regulated wire-feeding control

IN ARC WELDING

Low-voltage power supplies and high current densities make it possible to use simplified wire-feeding systems

BY R. W. TUTHILL AND R. D. MANN

INTRODUCTION. Fully automatic arc welding is defined as that where little or no human skill is required for operation. This is in contrast to manual welding with stick electrodes where a great deal of human skill is mandatory for successful welding. In fully automatic welding, the skill requirements are transferred from the welding operator to the automatic machine designer. In order to do this, the designer of the welding machine tool—in addition to furnishing proper work handling and fixturing functions—must provide for complete control of the welding variables. These variables are heat input to the work and heat output from the work. Heat input is mainly controlled by welding current, voltage and travel speed. Heat output is controlled by uniform clamping pressures, thermal conductivity of material to be welded, preheat or quenching rate and travel speed.

Circuit Characteristics

Since one characteristic of automatic welding is high speed, this makes the electrical requirements of the arc very rigid. Welding current and voltage must be kept constant. In manual welding, the setting on the power source controls current and the welding operator controls arc length (arc voltage) by manual manipulation. In automatic welding, these variables must be controlled by a machine. In any case, in both manual and automatic welding, the rate of feeding the electrode and the rate of electrode consumption must be equal. In manual welding, the ability to balance these two distinguishes a good welder from a mediocre one. In automatic welding, the electrode feeding device must balance wire feeding speed and wire consumption rate in order to maintain constant arc length.

In automatic welding systems used in the past, the method of control has been to *regulate the speed* of the wire feeding device, using a feed-back signal, to make the feeding speed of the electrode equal to the burn-off rate. An elementary schematic diagram of such a system is found in Fig. 1. This system has some serious limitations. For one, it is subject to hunting problems. Usually, a signal is taken from arc voltage compared with a standard and this information then is used to signal the wire-driving motor to speed up or slow down, depending on the way the arc voltage is changing. In order to keep the system from hunting, a significantly wide arc-voltage dead band must be used. This then permits considerable variation in the arc length and can lead to weld quality variations. As a result, considerable operator skill requirements were built up since dial adjustments were made to supplement the automatic control. This system had two dials—one for adjusting electrode feeding speed and the other for adjusting arc voltage. Each adjustment affected the other and were, therefore, not completely independent.

Recently, a new method of arc-length control has opened new horizons for fully automatic welding. This new method *regulates the welding current* automatically to control the burn-off rate of the electrode and makes this burn-off rate match the fixed wire-feeding speed. Regulation is faster and is less subject to hunting problems since it has practically no dead band. In addition, the two dials adjusting wire-feeding speed and voltage are independent of one another, which is a very real advantage. It is accomplished by having a source of welding power with an open-circuit voltage at no load only slightly above the arc voltage at full load. This type of power is very different from the conventional welders which have an open-circuit voltage usually two or three times arc voltage and drop to arc voltage under load by means of internal impedance or resistance.

One very important point must not be overlooked if this new system is to be used successfully. High current density must be used on the electrodes since heavy short circuiting of the arc by molten drops of metal cannot be tolerated, or a wildly-fluctuating arc will result. To prevent short circuiting of the electrode, current densities of 40,000 to 400,000 amp per square inch are employed. The operation at high current density forces the use of smaller electrodes than that previously used since the total currents that can be used are dictated by the thickness of the work, and they remain about the same as with other methods of welding.

As an interesting sidelight in the control of variables for quality welding, it has been determined that the actual arc length during welding should be held constant along with arc current; however, constant arc length does not necessarily mean constant arc voltage. So long as arc current does not change, the arc voltage will remain fixed for a certain arc length. However, if arc current increases due to an increase in the wire feeding speed, then the arc length will decrease even though arc voltage is held constant. If the wire feed is decreased, the arc length then increases. Therefore, on some applications which have changing wire feeding speed—particularly, at the end of welding such as crater filling—it is desirable to use a *constant-arc-length* welding machine rather than a constant-voltage welding machine. A constant-arc-length machine has a rising volt-ampere characteristic curve; in some cases, the arc voltage rises as much as $7\frac{1}{2}$ volts per hundred amperes.[1]

In high-current-density welding, the burn-off rate of

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Presented at the AIEE Electric Welding Conference held in conjunction with the 1957 AWS National Spring Meeting in Philadelphia, Pa., April 8–12.

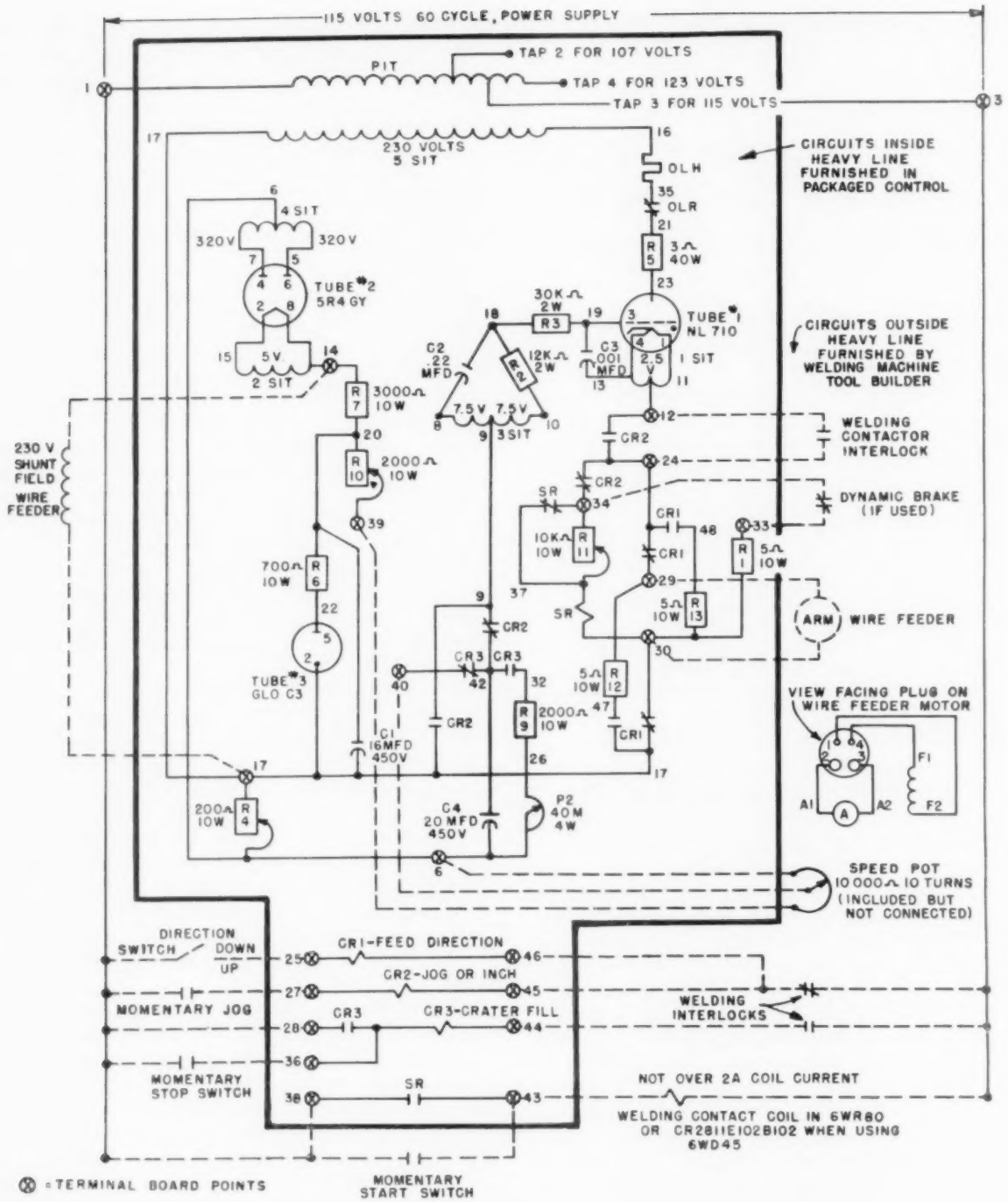

Fig. 2 Circuit of constant wire-speed control

the electrode is controlled by the welding current. Arc voltage has little effect in controlling this variable. Therefore, welding current is held constant in the high-current-density system by feeding the wire at a fixed constant speed. Since current controls burn-off rate, it automatically provides the feed-back signal, without any mechanical inertia, to make burn-off rate match the fixed feeding speed. The voltage difference between the terminals on the welder and the arc voltage forces current to flow in the arc. Therefore, if the burn-off rate is too fast, the arc lengthens and the current drops, since arc voltage approaches terminal voltage in value. The current reduces and this then, in turn, makes the burn-off rate reduce until it is the same as the feeding rate. If the burn-off rate is too slow, the arc shortens, the arc voltage drops and a greater current flows to correct the condition. In practice, very little variation in arc voltage and length is observed.

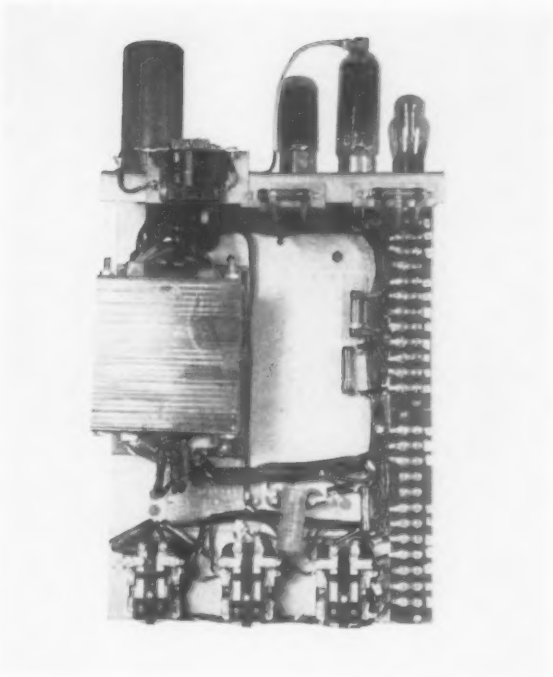

Fig. 3 Control panel for constant wire-feed speed

Simplified Circuit

The complexity of the circuitry required for the older automatic low-current density welding system shown in Fig. 1 is in sharp contrast to the simple circuit shown in Fig. 2. This circuit which is in wide use in high-current-density welding, operates the motor which feeds the electrode and controls other functions associated with the system. This new system employs a half-wave phase-shifting thyratron type of circuit for motor speed control. Figure 3 shows the physical arrangement of the control panel, with the relays, electronic circuits and main transformer assembled on one panel. It is intended that this panel be incorporated in the other control equipment for the automatic welding fixture.

The circuit operates to hold constant wire-feeding rate by comparing the speed of the motor, measured 60 times a second, with the setting on the speed-control potentiometer and then firing the thyratron NL-710/6011 tube 60 times a second to maintain the correct speed. An extra tube (OC3) is used in the circuit to permit wide variations in line voltage without affecting the speed. Regulation under varying load conditions is also excellent for this circuit. This circuit also incorporates controls for inching or jogging the wire, and slowly stopping the wire feed (crater filling) at the end of welding. This particular function has been made fully automatic by using a hermetically sealed voltage-sensitive relay (SR) to measure wire-feeding speed by means of the generated voltage of the driving motor on those half cycles when it is not conducting current. In reality then, the sensitive relay measures the rpm of the driving motor so that when the feeding speed reduces to a predetermined rate, the relay simultaneously and dynamically brakes the feeding motor and opens the welding contactor at the correct time to produce maximum crater filling. The circuit is adaptable to a number of different methods of operation with respect to sequence of starting of slow feed starts and the operation of other associated functions as initiating the travel mechanism or gas and water valves.

Electrical requirements, in addition to those of the arc, must also be considered since the end product must be safe, dependable, rugged and easy to maintain. In order to minimize damage to the equipment, proper fuses or overload devices must be provided. Voltmeters and ammeters provide proper data for quality control purposes.

Simultaneously with the advent of the low-voltage power supply and high-current density was the substitution of gas for chemical fluxes. This plays an important part in the push toward full automation since it completely eliminates the complex mechanism of flux removal and flux-handling equipment. The gas usually used for steel welding is carbon dioxide. The gas used for aluminum is argon, helium or mixtures of them, while stainless steel usually requires mixtures of argon and oxygen or argon and carbon dioxide.

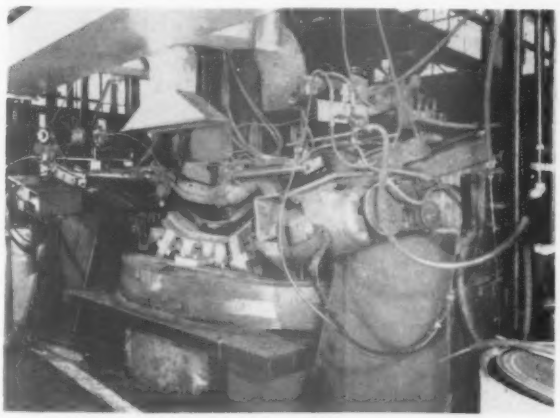

Fig. 4 Cross frame of automobile chassis being welded with four CO_2 gas-shielded arcs simultaneously

Applications

This new method of automatic control of the welding arc has had numerous applications. Since the manufacturing of automobiles is highly mechanized, it is not surprising to find the industry pioneering the application of this new process. Figure 4 shows a fully automatic welding fixture making four welds simultaneously on a cross member for the chassis of an automobile. The operator only has to load the fixture; it cycles automatically, including unloading. This is an advanced application of the carbon-dioxide gas-shielded welding process. It consists of four individual

Fig. 5 Finished automobile frame cross member

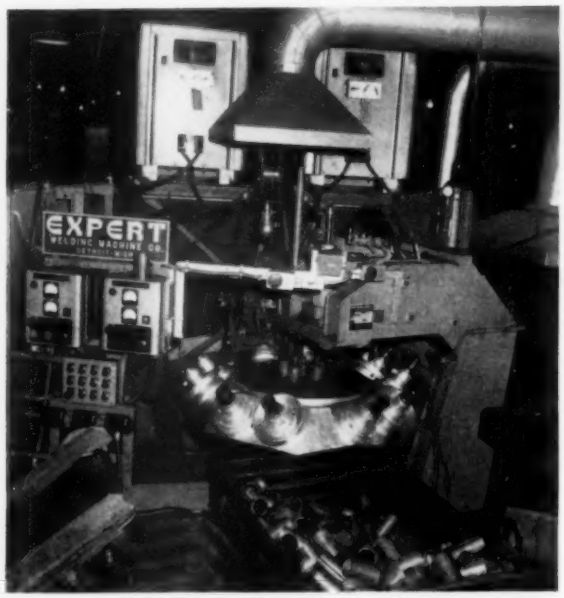

Fig. 6 Welding machine, with CO_2, welding two shock-absorber parts at once

Fig. 7 Finished shock-absorber welded parts

controls, initiated simultaneously but with the arcs started in sequence. Each arc goes to the common part (the cross member) and welding is accomplished in approximately $3^1/_2$ sec. The weld is approximately 17 in. long and this gives a welding travel speed of approximately 280 ipm. This travel speed is for each arc. The conditions of welding are: $^3/_{32}$-in. diam bare electrode, 780-amp welding current, 23-v arc voltage, 25-cfh carbon dioxide for each arc. Figure 5 shows a close-up of a finished cross member. Since welding is accomplished in such a short time, the loading time becomes appreciable. Although duty cycle is important, the factor to be considered is the number of parts produced per hour which, in this case, is 600. Gas-shielded welding permits a high production rate since the absence of flux and associated equipment greatly simplifies and speeds up the over-all operation. One interesting feature of this application is the use of low-voltage variable-ratio transformer-rectifier welding machines as a power supply for each arc. These are of the rising volt-ampere characteristic type.[2] This type of power source is ideally suited for high current and high duty cycles and is rated 800 amp continuously. Even small changes in arc voltage are sufficient to change the characteristics of any type of welding so as to affect quality under some conditions. In the high-current-density welding arc, the arc length and arc voltage are controlled from the power source and not from the welding-head control. The welding-head control only feeds the wire at a constant fixed speed and the arc voltage is dependent upon the power-source output voltage when it is producing the current that the wire-feed rate requires. Consequently, any change in power source setting only changes arc voltage, and the welding current is controlled by the rate at which the wire is fed into the arc. As a result of this, an uncompensated transformer-rectifier welding machine is sensitive to line-voltage variations which produce fluctuations in the welding-arc voltage and, consequently, change the characteristics and quality of the resultant weld. For this reason, for a number of years, motor-generator welding machines which are immune to line-voltage variation effects have been used for power sources for this type of equipment. More recently, however, variable-ratio transformer-rectifier welding machines have been applied with servo-mechanisms to correct for line voltage variations so as to permit welding to be accomplished with reasonably constant arc voltages.

Figure 6 shows another automatic welding machine with a constant wire-feeding system and the special regulated-voltage power supply seen in the top part of the picture. This is another automotive application—this time on a shock-absorber support. Figure 7 shows a finished welded assembly.

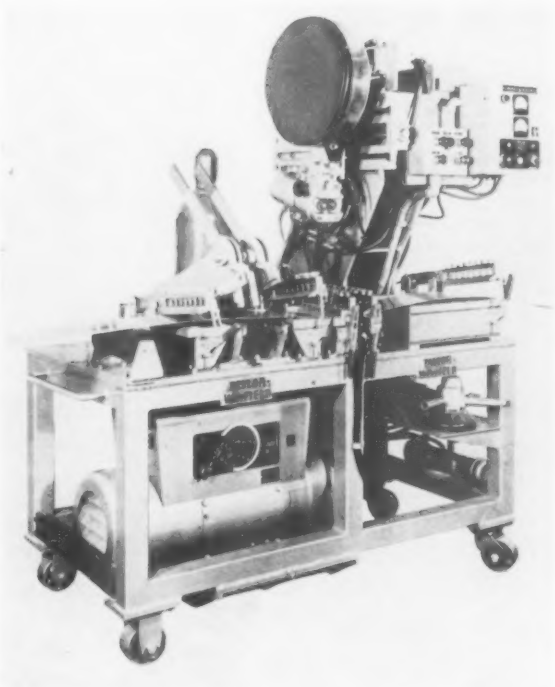

Fig. 8 Automatic welder for joining aluminum sheet $^3/_{32}$-in. thick with the argon-shielded consumable-electrode process

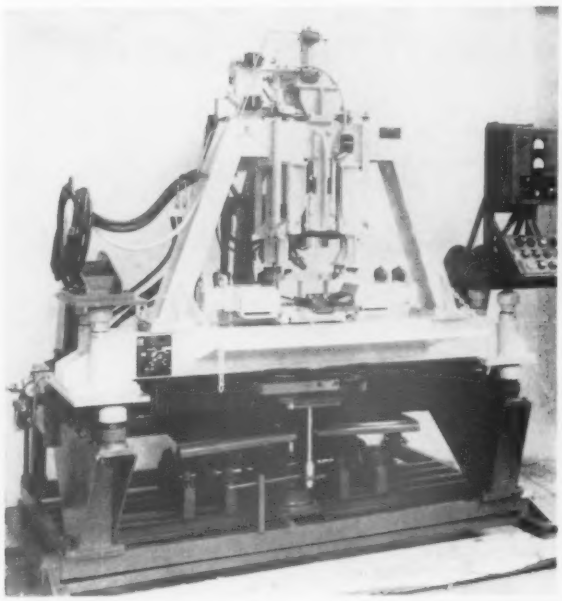

Fig. 9 Welding machine for CO_2 welding of pressure vessels for refrigerator compressor

Dimensions are $2^3/_8$ in. diam, $4^1/_4$ in. long, 0.093 in. wall thickness; the washer is $^3/_{16}$ in. thick. The fillet weld is $^1/_8$ in. Two cans are welded simultaneously in 5 sec and the complete cycle time is 7 sec. Welding current is 460 amp with a 23-v arc. The wire is high-silicon, high-manganese steel, $^1/_{16}$ in. diam. The carbon-dioxide flow is 35 cfh.

Welding fixture shows the 800-amp rectifiers in the background. A colored transparent shield to protect the operator from the arc rays was removed for picture taking. The operator sits between the tote box containing washed tubes and the table to his left that holds the washers. His job is to partially insert the tube and washer in the spring loaded collets as they pass in front of him. The revolving turret automatically sequences through five stations. The second station to his left is an "extra." At the third station, a hydraulic-operated piston presses the tubes down into the spring-loaded collets. The fourth station does the welding. The fifth station ejects the welded parts. The operator initiates the fixture by stepping on a foot-operated push button. To stop, he presses a palm button directly above him.

Left foreground is a portion of conveyor that carries the formed tube from the punch press to the tote box. These parts are greasy and will be taken to another area for washing before welding.

Figure 8 shows a welding-machine fixture for seam welding the ends of aluminum sheet (0.040 thickness). This is to make longer sheets—a practice quite common in industry and one to which the gas-shielded process is ideally suited. Although, on this fixture, the welding seam is perpendicular to the edges of the sheet, on some applications where re-rolling is going to be done, the seam is made on a bias to reduce rolling stresses.

Figure 9 illustrates a fully automatic welding machine for the final assembly operation of a refrigerator compressor. The lower half of the housing, with the motor compressor and valves installed, is loaded in the fixture together with the top part of the housing. The welding is then accomplished with carbon dioxide and a bare-steel filler wire. The finished part is then unloaded from the fixture by hand.

Summary

In summary, the use of low-voltage power supplies has been made practical by employing high current density. Together, these have made it possible to use simple wire-feeding systems with no feed-back control circuitry needed. This simplification results in much more reliable welding with little or no skill requirements for the welding operator. The use of gas shielding eliminates problems encountered with flux. This new welding method greatly simplifies the electrical requirements for automatic arc welding and will, therefore, permit arc welding to keep pace with other manufacturing processes in the trend toward the automatic factory.

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THERMAL ANALYSIS OF BRAZING AND HARD-SURFACING ALLOYS —A PROPOSED METHOD

Procedure advanced by author described as being a simple, practical and accurate means for determining liquidus and solidus temperatures for brazing and hard-surfacing alloys which melt within the range of 1600 to 2100° F

BY FORBES M. MILLER

The advent of our so-called "jet age" or "atomic age" has brought with it the need for operation of engines, motors, machinery and equipment at higher and higher temperatures. Many of the new brazing alloys, developed to meet the new requirements, are high-temperature-resistant metals. Many hard-surfacing alloys are also high-temperature-resistant metals. These have become increasingly important to the welding engineer and product designer as a result of their growing acceptance in industry as basic materials for original equipment manufacture.

There has never been an established practical method for determining melting characteristics of brazing and hard-surfacing alloys. The need for such a method is evidenced by the trend among certain users toward quality control requirements calling for specification of a given alloy's melting range. The method and equipment described in this paper have been developed as a simple, practical and accurate means for determining liquidus and solidus temperatures for brazing and hard-surfacing metals which melt within the range of 1600 to 2100° F.

Existing Methods Impractical

Simple cooling curve procedures have been used for many years to study the characteristics of very low-melting metals, such as solders. With these methods, the metal is melted in some convenient furnace and a protected thermocouple immersed in the melt. The furnace is then turned off and the metal allowed to cool with the melt exposed to ambient conditions. An ordinary temperature/time cooling curve is then plotted using a standard recording pyrometer.

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Presented at the 1957 AWS National Spring Meeting in Philadelphia, Pa., April 8–12.

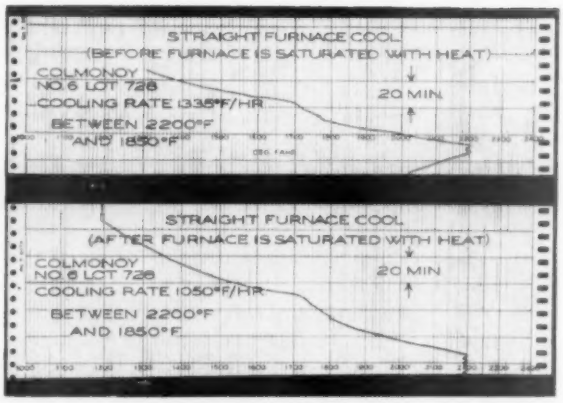

Fig. 1 Two typical curves obtained with straight furnace cooling. Significant phase reactions are difficult to recognize

The problem with this type of method as applied to high-temperature metal alloys of relatively complex structure is twofold: (1) the cooling rate is too variable for accurate analysis, and (2) the shape of the cooling curve is such that accurate determination of phase reactions is all but impossible. This method is satisfactory, however, for pure metals and alloys that are not complex.

Figure 1 shows two curves obtained using a straight furnace cool; one in which cooling was begun after the furnace had been allowed to become saturated with heat, the other in which cooling was begun as soon as the melt registered 2200° F. Significant phase reactions are difficult to recognize in these two curves.

In approaching the problem of devising a new and more satisfactory method, various accurate procedures such as those used by the Bureau of Standards, colleges

Fig. 2 Over-all view of equipment developed for thermal analysis of high-temperature brazing and hard-surfacing alloys

and other research institutions were studied. It was decided early that these were too costly, elaborate and time-consuming for routine material quality-control procedures in the average industrial plant.

It was then decided that the solution to the problem must lie in the development of an original method that would permit a controlled rate of cooling for the melt so that the resultant curve would be a straight-line function. Phase reactions would then be readily discernible and could be picked out accurately without an excessive expenditure of finances and time.

Initial Investigations

In the first attempt at an original method, the concept of using a program controller connected to a recording pyrometer was considered. This was not actually tried, but thorough study indicated that in such an arrangement the program controller tends to lose its function within the solidification range. The accuracy of this conclusion has been verified by numerous researchers in this field.[1]

The work of Cyril Smith[2] in the thermal analysis of steels was then studied. It was decided to try a setup similar to his wherein a differential pyrometer controller is used to control the rate of cooling. The controller and furnace are linked in circuit with a fast-acting recording potentiometer to plot the cooling curve. The curve is a temperature/time plot. With proper modification, this proved to be the satisfactory solution to the problem.

Equipment and Apparatus

In brief, the apparatus used in this thermal analysis method consists basically of an electric melting furnace, a means of providing differential control of cooling, and a high-response temperature recording mechanism for plotting cooling curves. Figure 2 is an over-all view of the complete laboratory setup with the equipment in operation.

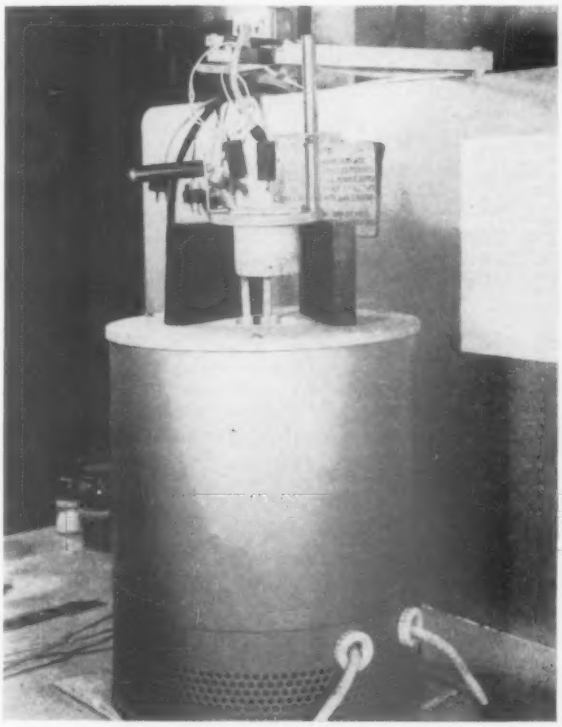

Fig. 3 High-temperature electric crucible furnace used for melting and controlled cooling of metal samples. Metal plates visible on top of furnace are not part of equipment; they are merely used here to prop up thermocouple assembly for illustrative purposes

For melting the metal, a high-temperature electric crucible furnace is employed (Fig. 3). Its capacity is

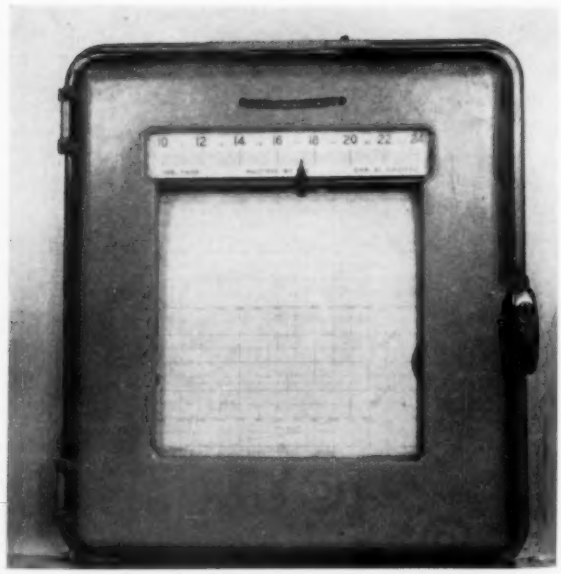

Fig. 4 Recording potentiometer used in program. This unit has been modified to produce maximum indicating speed of 38 indications per min

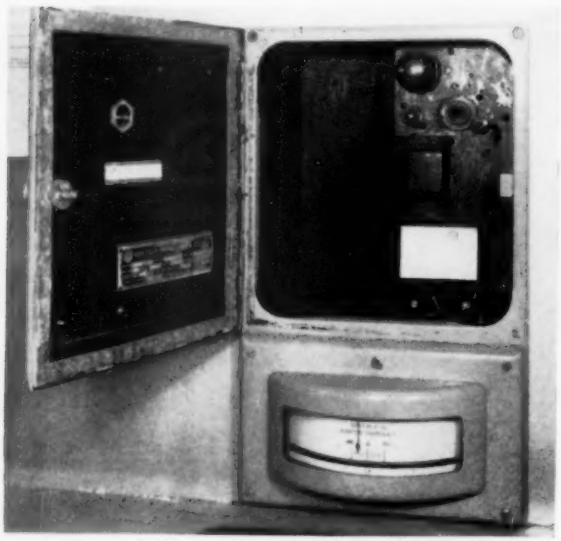

Fig. 5 Pyrometer used for differential control of the cooling rate of the melt. It provides a range of control of temperature differentials from zero to plus 200° F and zero to minus 200° F

rated for temperatures up to 2350° F. Suitable elements are used.

The heating chamber of this furnace is 3 in. in diameter and 4 in. deep. The furnace must be of a size sufficient to uniformly heat the specimen which usually consists of $^1/_2$ to 1 lb of metal. The size selected for this application is the one that most closely meets this requirement in a standard, commercially available furnace.

One important requirement of the furnace used in this method is that it must be designed for fast cooling to insure positive differential cooling control. This is quite the reverse of the usual furnace requirements. The unit used has a minimum of insulation in a commercially available furnace. A furnace specially built for this application would be designed with still less insulation. Fast cooling is a prime requisite because for effective control of the cooling cycle, the normal cooling range must exceed by many times the desired controlled cooling rate. The furnace should be equipped with a rheostat to control power input.

Control and Recording Devices

Another element in the equipment package is a commercially available recording potentiometer which has been modified to produce maximum indicating speed of 38 indications per minute or about one every 2 sec (Fig. 4). The scale range on this recording device is from 1000 to 2400° F.

The differential controller used consists of a standard, commercially available pyrometer, modified in such a manner as to provide a range of control of temperature differentials from 0 to +200° F and 0 to −200° F (Fig. 5). The two-direction range is necessary to allow for the maintenance of differentials both where the outside thermocouple is hotter than the inside (0 to +200° F) and where the reverse is true (0 to −200° F). This is desirable because in setting the differential control to obtain the desired cooling rate for a given metal, it may be necessary to select a position on either side of zero.

Thermocouples

Chromel-alumel thermocouples are used; one is placed in the center of the melt, the other outside the cruicible. It is important in locating the thermocouples that the ends of both be the same vertical distance above the bottom of the furnace. The center thermocouple (in the melt) is connected with a chromel-alumel lead wire directly to the recording potentiometer. The two thermocouples are connected with a copper wire and are led to the pyrometer with a copper wire.

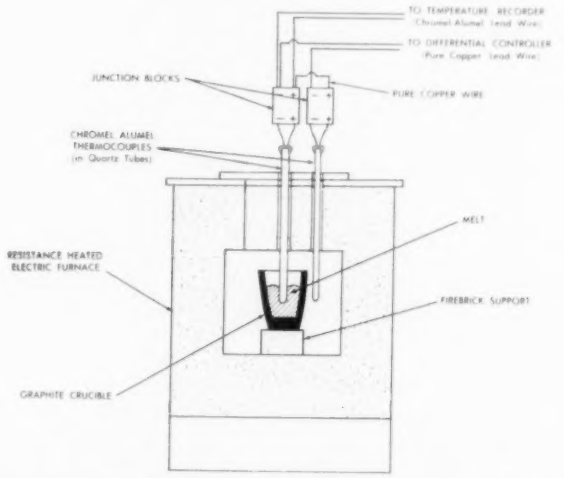

Fig. 6 Circuit drawing showing hookup of thermocouples to recording potentiometer and pyrometer

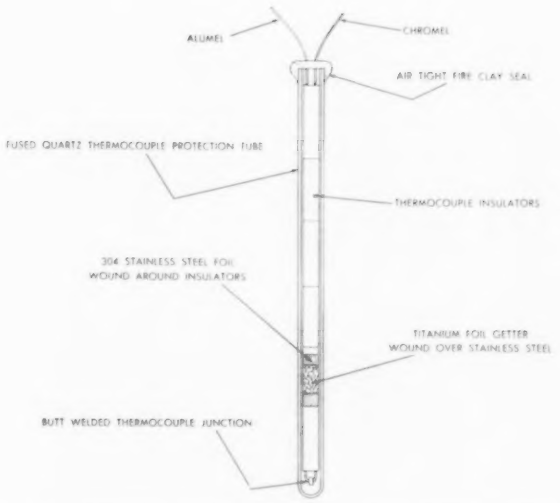
ALUMEL
CHROMEL
AIR TIGHT FIRE CLAY SEAL
FUSED QUARTZ THERMOCOUPLE PROTECTION TUBE
THERMOCOUPLE INSULATORS
304 STAINLESS STEEL FOIL WOUND AROUND INSULATORS
TITANIUM FOIL GETTER WOUND OVER STAINLESS STEEL
BUTT WELDED THERMOCOUPLE JUNCTION

Fig. 7 Assembly drawing of thermocouple assembly used. Note titanium "getter" at the insulator. This "getter" reacts with oxygen in the sealed quartz tube on initial heating, forming titanium oxide and preventing oxide formation and attendant emf loss in the thermocouple proper

Correct polarity must be established in this circuit (see Fig. 6).

An interesting sidelight to the development of this method concerns the matter of thermocouple protective tube design. The thermocouples used in this equipment are inserted in a quartz tube and sealed to protect them from contamination by the melt and to stabilize the temperature effect. Although the thermocouple element is thus protected from contact with outside contaminants, a small amount of oxygen still exists within the tube. Application of heat causes this oxygen to react with the thermocouple material to form an oxide on the thermocouple surface. The oxidized surface causes a variation in the electromotive force potential of the thermocouple.

The electromotive force potential variation in each thermocouple is small and is not a problem when variations are identical in the two thermocouples as connected together in the circuit. The loss resulting from oxidation, however, is rarely the same for any two thermocouples. This can be a serious problem in the equipment described because we are measuring temperature *differential*, which is the difference in the electromotive force produced by the two thermocouples. Where the temperature differential is relatively small, as it is in this case, any slight variation between the electromotive force potential of the two different thermocouples assumes greater magnitude in terms of percent error.

To preclude the possibility of oxidation and attendant variation in electromotive force potential, a titanium "getter" is introduced at the insulator between the quartz tube and the thermocouple (Fig. 7). Upon heating, the existing oxygen reacts with the titanium and not at all with the thermocouple. Thus, electromotive force loss is minimized if not completely eliminated. This design not only solves a potentially dangerous problem but substantially extends thermocouple life as well.

Method Procedure

The method which has been developed as a result of our research efforts is best described by outlining the separate steps in the procedure in one-two-three order. Proper sequence and control of the procedure is important to permit accurate comparison of results. The ability of the method to repeatedly produce liquidus and solidus values for a given alloy sample that are consistent within a reasonable limit of variation is a direct measure of its effectiveness. The procedure is as follows:

Fig. 8 Typical specimen and graphite crucible used in research and development activities. This ingot measures $1^1/_2$ in. in diam by $1^1/_2$ in. long. It weighs 250 g

1. Obtain a sample of the metal to be analyzed. This may be initially obtained in the form of powder, rod or odd pieces and should be from the same production batch if you are an alloy producer or from the same shipment if you are an alloy user. The mass must be at least sufficient to completely immerse the thermocouple and to surround it with at least $^1/_4$ in. of melted metal. For the size 4-0 graphite crucible used in the electric crucible furnace previously described, a 250-g sample has proved practical. This will produce an ingot approximately $1^1/_4$ to $1^1/_2$ in. in diameter, $1^1/_4$ to $1^1/_2$ in. long. The sample can be larger and dimensions may vary with the specific application, but for our purposes the foregoing specifications seem to give the best results. A specimen typical of those used in our research is shown in Fig. 8.

2. Premelt the sample in the crucible in an atmosphere of pure dry hydrogen. This is required to clean the metal and produce a basically-sound homogeneous ingot.

3. Place the crucible containing the ingot in the exact

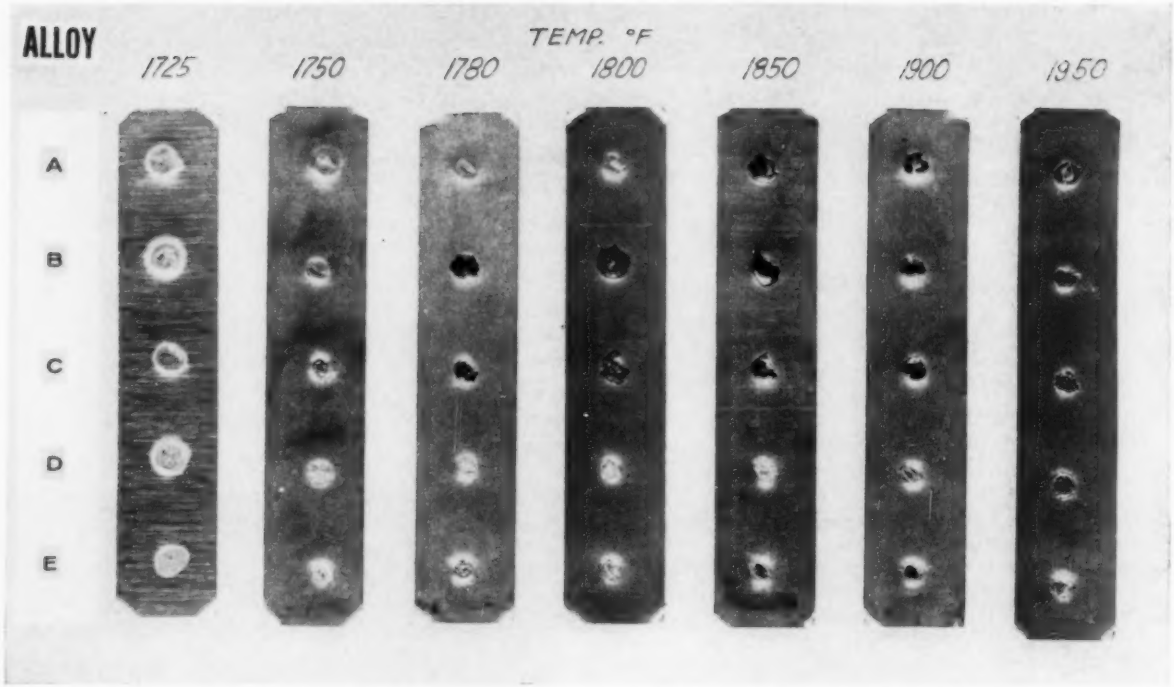

Fig. 9 Series of samples on dimpled stainless steel strips used to determine melting range of new alloys

center of the furnace. The inside thermocouple should be placed to rest on top of the ingot and the outside thermocouple positioned half way between the top and bottom of the ingot. The crucible should be placed on a piece of refractory or metal to raise it off the furnace floor far enough to position the ingot in the approximate center of the heating chamber.

4. Turn the rheostat to 100% power. Connect the furnace control wire to the recording potentiometer and set the temperature for 2000° F. With this completed, turn on the power.

5. As soon as the crucible temperature reaches that at which the alloy is partially melted, lower the inside thermocouple to immerse it in the melt. Its position should be in the exact center of the crucible with its lower end the same distance above the furnace floor as that of the outside thermocouple.

6. When the temperature of the melt reaches 2000° F, allow the ingot to soak at that temperature for about 15 to 20 min to equalize the temperature throughout the furnace and its contents. Adjust the furnace power input to 85% to prevent possible overheating surges. Raise the temperature then to the controlled cooling start temperature of 2100 to 2200° F. During heating, watch the temperature differential indicator to see that the difference in temperature between the two thermocouples does not exceed 100° F. Maintaining this differential will prevent the outside thermocouple from overheating and melting. Allow the melt to soak at this temperature for another 15 to 20 min.

7. Disconnect the control circuit from the recording potentiometer and connect it to the pyrometer. Paper speed on the recorder should be adjusted to produce a curve at the beginning that assumes an angle of approximately 45 deg on the chart. In our case, a speed of $1\frac{1}{2}$ iph proved satisfactory.

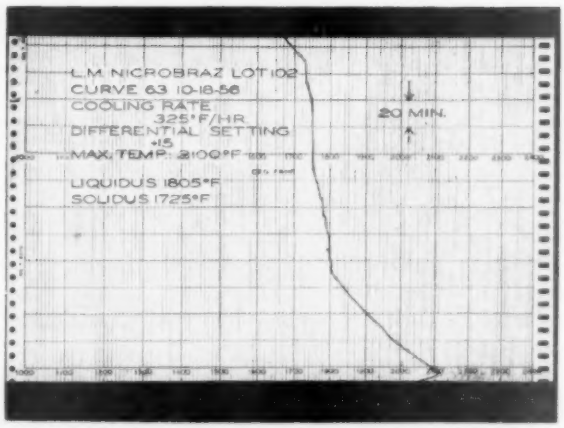

Fig. 10 Typical cooling curve produced on recording potentiometer where cooling rate was 325° F per hr

8. Set the differential controller for a figure that will give the desired rate of cooling. The actual differential setting for a given alloy and set of conditions is determined by trial and error. A rule of thumb for initial establishment of a differential setting is to set the instrument for a small temperature differential to start. If the recorded curve shows that the melt is cooling too slowly, the differential setting should be

moved toward the negative scale; if cooling is too rapid, the setting should be adjusted toward the positive scale. During experimental work, we have experienced the need for settings varying from −30° F to +15° F temperature differential.

In establishing the differential setting, there must be some cooling rate target in mind. Theoretically, the slower the rate of cooling the more accurate will be the determination of liquidus and solidus temperatures. Practice has shown, however, that for our alloys a cooling rate of 200 to 400° F per hour is suitable for reasonably reproducible results.

If, during attempts to obtain a 250° F per hour cooling rate, the temperature of the melt should drop more than 100° F before the proper differential setting has been established, the melt should be reheated to bring the temperature back up to the starting point before proceeding.

9. Allow the melt to cool until the alloy has completely solidified and has passed all solid-state phase changes, if any.

10. Examine the cooling curve for liquidus and solidus temperatures and other types of reactions. In any newly developed alloy of complex structure, determination of the specific reaction which identifies the solidus temperature is not always possible from simple observation of the cooling curve. There may be a solid-state phase change that can complicate solidus temperature identification.

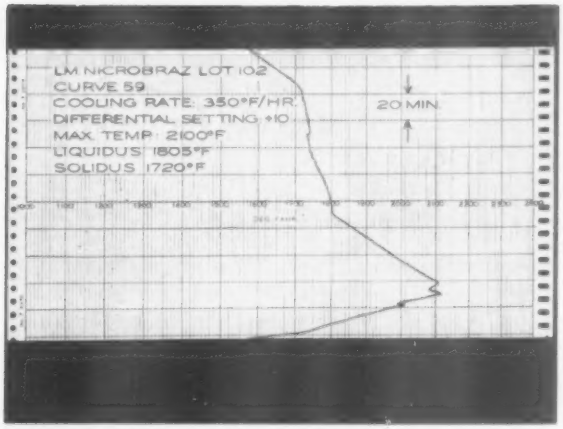

Fig. 11 Typical cooling curve where cooling rate was 350° F per hr

A simple check developed by our laboratory makes it easy to determine the temperature range in which melting occurs. This involves placing a small amount of the alloy in several dimpled pieces of stainless steel. The samples are then heated one at a time in pure dry hydrogen, each at a different temperature within the reaction zones indicated on the cooling curve. After heating, the samples are examined visually under a stereo-microscope for evidence of melting. The solidus temperature is then identified as the reaction that is just below the lowest temperature at which melting is evident. Figure 9 shows a series of samples after heating.

This test is also valuable in determining roughly how much melting occurs at various points within the melting range. For example, in some alloys the greatest portion of melting may occur at the solidus temperature; in others, the greatest percentage of melting may occur near the liquidus temperature, or it may vary uniformly between liquidus and solidus temperatures.

Summary

The results achieved with the method and apparatus described have been most encouraging. Control is very satisfactory and reproducible results are consistently achieved.

Figures 10 and 11 show results achieved with the equipment and method. Figure 10 is a typical cooling curve produced on the recording potentiometer using a cooling rate of 325° F per hour. The metal in this case was a nickel-chromium-boron-silicon brazing alloy. Maximum temperature for the melt was 2100° F and the differential setting was +15. The liquidus temperature determined by this curve is 1805° F and the solidus, 1725° F.

Figure 11 shows another cooling curve for the same nickel-chromium-boron-silicon brazing alloy. Maximum temperature was again 2100° F and the differential setting was nearly the same at +10. The cooling rate this time was 350° F per hour. The liquidus temperature indicated on this curve is again 1805° F; solidus temperature 1720° F, just 5 deg different from that found in the Fig. 10 curve.

Our experience with a wide range of cooling rates tends to indicate that the specific cooling rate used in a given application is considerably less important than maintenance of a uniform rate of cooling. It is still desirable, however, to have a target and we usually aim for 250° F per hour.

The capital investment required for the apparatus is relatively small, and the equipment is quite simple to operate. Cost of the apparatus is well within the range of a small laboratory's equipment budget. The method is proposed for use by companies who are seriously interested in expanding quality control to include accurate determination of liquidus and solidus temperatures of new as well as currently marketed brazing and hard-surfacing alloys.

Our goal in developing this method and equipment has been to provide a simple, accurate, low-cost means for determining the melting range and phase relationship in high-temperature metals. Based on experimental results to date, it appears as though this goal has been achieved. It now remains for the welding industry to accept it and put it to practical use.

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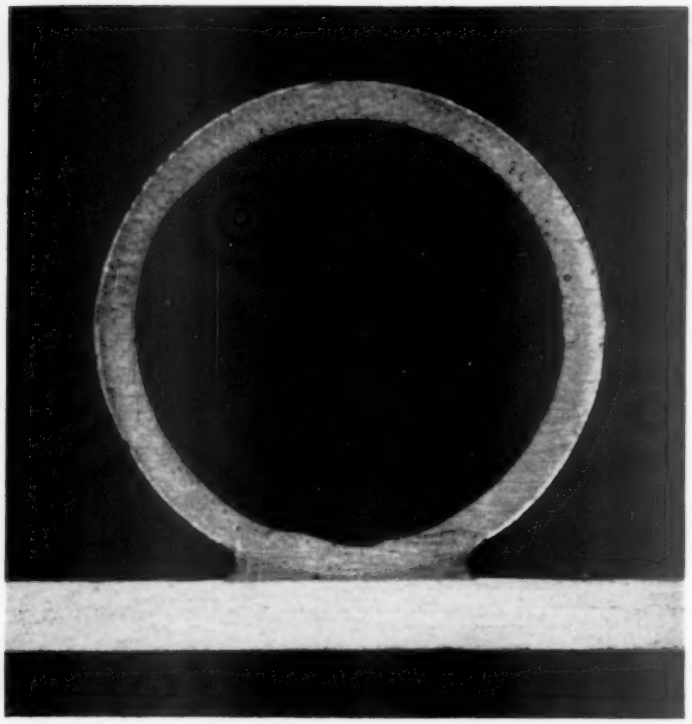

Fig. 1 Cross-section of galvanized steel pipe furnace-soldered to an aluminum plate

ZINC SOLDERING OF ALUMINUM

Zinc soldering is reported to be an excellent process for joining aluminum to itself and to many dissimilar metals, provided that proper fluxes, solders and procedures are employed

BY I. B. ROBINSON

ABSTRACT. Zinc soldering with the proper fluxes, solders and procedures is a simple method for joining aluminum to itself and dissimilar metals at intermediate temperatures to provide strong, easy-to-make, corrosion-resistant joints.

Zinc solders may consist of zinc or zinc alloys containing from 90 to 100% zinc with varying amounts of higher melting metals such as aluminum, silver, copper or nickel. These solders can be supplied to the joint from solder-coated aluminum sheet, as added wire or shims or from a molten solder bath. The fluxes are inorganic salts mixed with water or organic solvents for application. Furnace, torch, molten metal dip and resistance soldering can all be used. Tube-fin constructions, socketed tube joints, transition joints and cellular products are some of the many assemblies that have been joined.

Zinc-soldered joints between aluminum parts are stronger than where soft solders are used, and they are generally stronger than the commonly soldered aluminum alloys. These joints have good resistance to corrosion when high-purity solders and proper flux removal procedures are used. Zinc-soldered aluminum joints will last many years in ordinary atmospheres.

Introduction

Zinc soldering is the best method for making sound, corrosion-resistant soldered joints between parts made of aluminum and its alloys. This process is not new; in fact, it is one of the oldest means for joining aluminum. Yet it has never been fully utilized, perhaps because its merits have never been appreciated. This paper describes the zinc soldering of aluminum, noting both its advantages and its limitations.

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Presented at the 1957 AWS National Spring Meeting, Philadelphia, Pa., April 8–12.

Solders

Zinc solders are usually composed of zinc or alloys containing 90 to 100% zinc with varying amounts of high melting metals such as aluminum, silver, copper or nickel.[1, 2] These additions improve the ability to wet aluminum, lower the soldering temperature and provide a wider melting range without affecting resistance to corrosion. Only small amounts of these higher-melting-point metals should be added, however, since larger quantities rapidly raise the melting point of the solder. To obtain the maximum resistance to corrosion, 99.99% zinc and high-purity alloying additions should be used in preparing these solders.

In general, the properties of the zinc-base solders closely resemble those of zinc. The melting points generally range from 720 to 800° F, and the strength in

soldered joints is usually greater than that of the commonly soldered aluminum alloys. These solders, because of their high zinc content, are much cheaper than the common soft solders. Zinc solders can be provided in the form of wire, sheet and many other shapes.

Solder may be supplied to the joint area in different ways. For many applications, it is most convenient to employ it in the form of a cladding or coating on one or more of the aluminum component parts of the assembly. Zinc-clad aluminum sheet, which can be secured commercially, offers an excellent means of providing zinc in the desired joint area. This product is available with either one or both sides clad with various thicknesses of zinc; consequently, the amount and placement of the zinc can be controlled. Aluminum may also be coated with zinc by depositing it from a flux containing zinc chloride or by hot dipping in molten zinc with the aid of a flux, ultrasonic energy or rub "tinning" to secure the necessary wetting. Such coatings have a more limited application than zinc cladding since they contain some aluminum and therefore require a more active flux. For some applications, it may be desirable to supply the filler metal at the joint as a preplaced shim or wire. In applications where capillary flow is possible, the filler metal can be supplied from a molten solder bath.

Fluxes

Fluxes for zinc soldering generally contain inorganic chlorides and fluorides as the active constituents. These salts are usually mixed with water or organic solvents to form pastes or slurries that can be applied by dipping, brushing, spraying or other convenient methods.

A great many of these fluxes contain zinc chloride which reacts with the aluminum at a definite temperature, depending on the flux composition, to deposit zinc and to release aluminum chloride. Such a deposition of zinc facilitates the wetting of the aluminum and filling of the joint by the molten solder.

A differentiation is generally made between fluxes high in zinc chloride and those low in this salt. In the former, often referred to as reaction fluxes, nearly all of the flux is consumed in the reaction, leaving none to form a protective film over the joint area. Consequently, the solder must be at the joint when the reaction occurs. For this reason, it is difficult to hand-feed solder into the joint. With the low-zinc-chloride fluxes, on the other hand, only a small portion of the flux is consumed in the reaction. The remaining flux forms a protective blanket that allows the solder to be hand-fed into the joint.

These fluxes are hygroscopic and should be kept in tightly closed containers. This is especially true of the fluxes containing a large amount of zinc chloride, where any absorption of water develops oxychlorides that interfere with soldering. To overcome this disadvantage, organic liquids are sometimes used instead of water in preparing slurries of high-zinc-chloride fluxes. Normal-propyl and normal-butyl alcohol have proved to be satisfactory vehicles for many fluxes. They have relatively low vapor pressures, burn cleanly when the fluxed assembly is heated, are inexpensive and readily wet slightly oily surfaces.

Flux residues left after joining must be removed since they seriously lower resistance to corrosion of soldered assemblies. The residues from an alcohol slurry of flux can generally be removed by washing in hot water. However, if an appreciable amount of oxychloride is formed or if the low-zinc-chloride fluxes are used, a more thorough flux removal treatment is necessary. A satisfactory procedure is to wash in hot water, dip in dilute sodium hydroxide solution, water rinse, dip in dilute phosphoric acid solution, water rinse and air dry.

Alloys That Can Be Soldered

Any of the commercial forms of nearly all the aluminum alloys can be joined by zinc soldering.[3] The high strength, heat-treatable alloys are not generally recommended for zinc soldering. The solderability of aluminum alloys is slightly reduced by the presence of appreciable magnesium and is more strongly affected by the presence of silicon. In general, castings are more difficult to solder than are wrought products. The temper of an aluminum alloy has no effect, in itself, on solderability; however, heat-treating films, particularly on alloys containing magnesium, reduce effectiveness of the fluxes. These heat-treating films can be removed by treatment with sodium-hydroxide or hydrofluoric-acid solutions.

Zinc soldering is a satisfactory means for joining aluminum to other metals[4] such as copper, silver, mild steel and stainless steel; but close temperature control is required where brittle intermetallic compounds are formed.

Soldering Procedures

Zinc soldering can be effected by such common

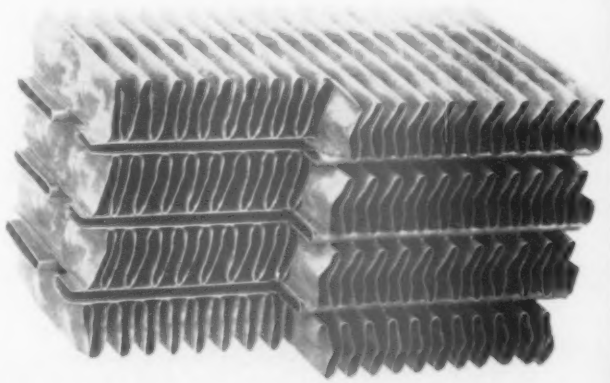

Fig. 2 Furnace-soldered tube, and corrugated-fin assembly. Zinc-clad sheet was used to form the tubes

Fig. 3 Spiral-fin tubing, furnace soldered with a high zinc chloride flux

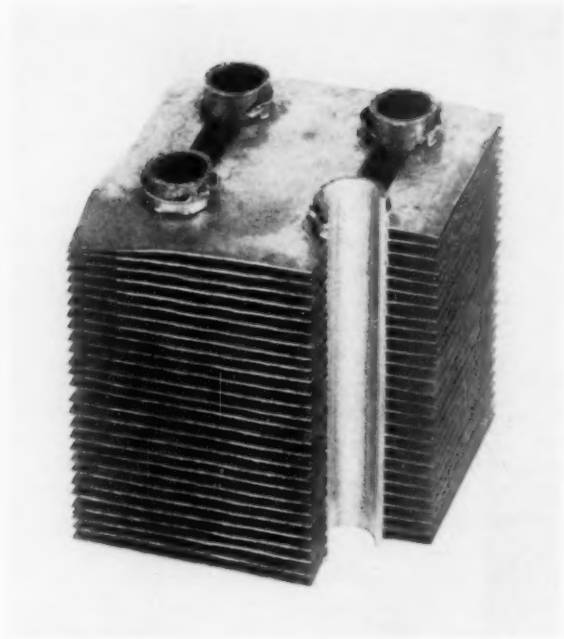

Fig. 4 Furnace-soldered tube and plate-fin assembly

procedures as furnace, torch, dip and resistance soldering. This versatility points to promising new applications for aluminum in refrigeration, air conditioning, automotive and many other fields.

Furnace Soldering

Furnace soldering, perhaps the most widely used process, offers a number of advantages. One of the more important of these is that a number of joints can be made simultaneously, regardless of their length. Furthermore, since the solder and flux are in place when the joining procedure starts, the amount of filler metal can be controlled. The accurate control of times and temperatures restricts, if it does not prevent, any diffusion of the solder into the base metal.

For furnace soldering, the component parts are assembled and fluxed. If any alcohol is used in applying the flux, it should be driven off before soldering begins either by a preliminary heating operation or by igniting it in the furnace. After the assembly has been introduced into the soldering furnace, it should be heated to the desired temperature as rapidly and as evenly as possible. A forced circulation of hot air is convenient for providing such heating. To minimize any diffusion of zinc into the base metal, the temperature should be as low as possible, and the assembly removed from the furnace as soon as the soldering has been completed. A flux cleaning operation completes the process.

For assemblies requiring a large amount of filler material, a preplaced shim or wire of the solder can be added to the joint area. This procedure was used in joining the galvanized steel pipe to the aluminum plate shown in Fig. 1. There is iron pickup by the solder from the steel, and an intermetallic layer, 0.0003 in. thick, between the solder and the steel pipe.

Zinc-clad aluminum is convenient in assemblies where some parts can be formed from flat sheet. Since the solder is present as a cladding, the filler metal is exactly where it is needed in the joint. Tube and corrugated-fin assemblies (Fig. 2), such as those in automotive radiator cores, have been made with bare aluminum fins and tubes formed from zinc-clad sheet.

For many joints requiring only a small amount of filler alloy, the need for added solder is eliminated by a high-zinc-chloride flux which reacts to supply the required solder. Additional solder, if needed, may be obtained by adding zinc powder to the flux slurry. Joints made in this way are common in many fin-tube assemblies. Spiral-fin tubing having aluminum fins joined to aluminum, copper or steel tubes is one example (Fig. 3), and tube and plate-fin assemblies of all-aluminum construction or with aluminum fins bonded to dissimilar metal tubes is another (Fig. 4). In these assemblies, the zinc that is deposited on all aluminum surfaces covered by this flux is immediately melted. This zinc combines with the aluminum to form a zinc-aluminum alloy layer. Under surface tension, this molten alloy flows into the joints to form fillets like those shown in Fig. 5. The aluminum surfaces retain an alloy layer about 0.0004 in. thick, as is shown in Fig. 6. This layer improves the resistance to corrosion of the assembly.

Torch Soldering

Torch soldering provides a logical answer to the problems encountered in secondary soldering operations, such as the joining of tubes, fittings and other attach-

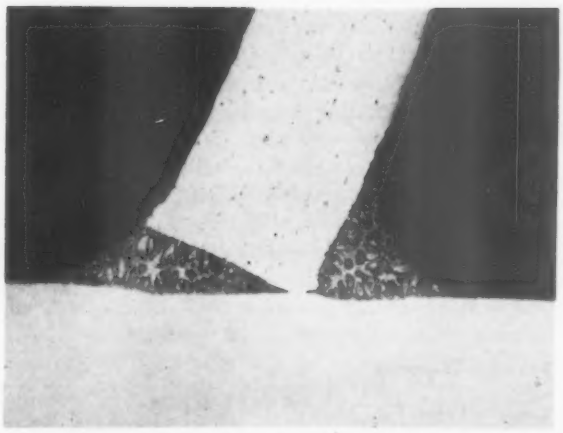

Fig. 5 Cross section of an aluminum fin (top) zinc soldered to an aluminum tube with a high zinc chloride flux. Nitric etch. X100. (Reduced by $^1/_4$ upon reproduction)

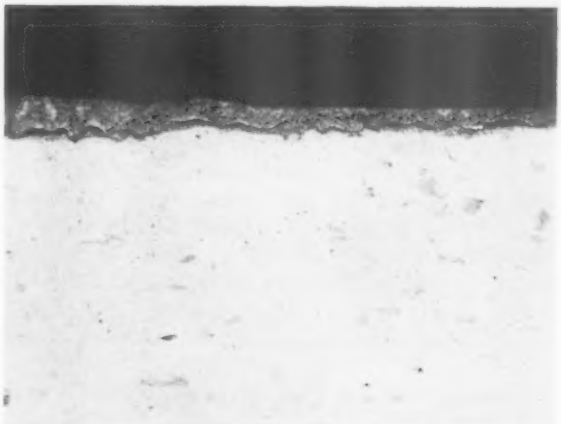

Fig. 6 Typical zinc-aluminum layer (top) on an aluminum fin soldered to a tube with a high zinc chloride flux. Nitric etch. X500. (Reduced by $^1/_4$ upon reproduction)

ments to assemblies that have been previously soldered by some other means. This process is particularly suitable for soldering socketed tube joints (Fig. 7) where a high-zinc-chloride flux and preplaced filler metal can be used. Examples of such joints are found in air-conditioner and heat-exchanger assemblies employing aluminum return-bend joints and transition joints between aluminum and copper or stainless-steel tubing. For making soldered joints and repairs in soldered assemblies with a hand-fed filler wire, it is necessary to use a low-zinc-chloride flux.

The torch soldering of socketed tube joints requires that the tubes be assembled, the solder placed in the flared socket and the joint area coated with a high-zinc-chloride flux. The assembled joint should be heated rapidly, either with a hand torch or by burners in an automatic soldering jig. An oxyhydrogen, oxyacetylene or oxy-natural gas flame may be used. A reducing flame is advised to give a less concentrated heat source. With the high-zinc-chloride flux, best results are obtained by heating the workpiece away from the joint area and allowing the heat to be conducted to the

Fig. 7 Cross section of a torch-soldered aluminum socketed-tube joint. Zinc solder was preplaced at top of flare. Note complete flow of solder

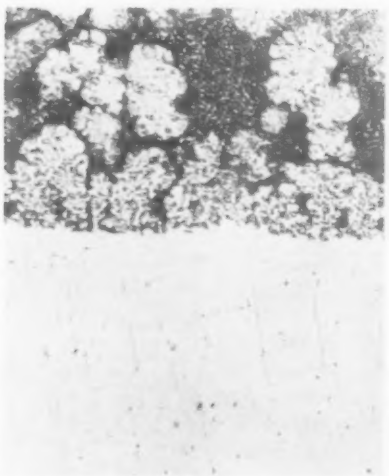

Fig. 8 Intermetallic compound layer (center) between zinc solder (top) and copper (bottom). Nitric etch. X500. (Reduced by $^1/_4$ upon reproduction)

joint through the metal. This precaution is necessary because moisture in the flame can react with the flux to form oxychlorides; these prevent joining and make removal of flux residues more difficult. As soon as the joint reaches the reaction temperature of the flux, zinc is deposited on all of the fluxed surfaces, thus insuring complete wetting and filling of the joint by the solder.

During the soldering cycle, there will be solution of

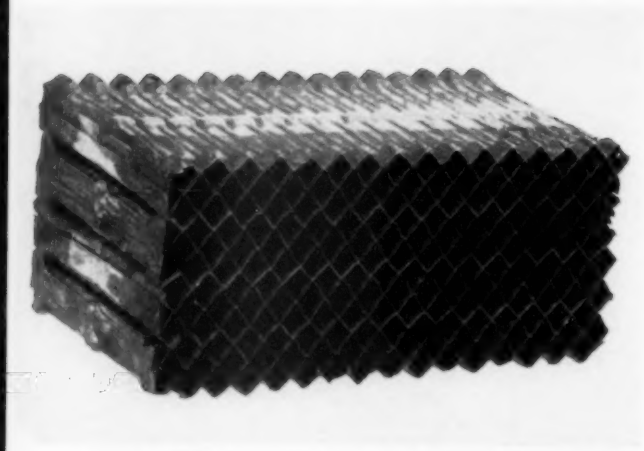

Fig. 9 Cellular assembly joined by molten-metal dip soldering with a zinc solder

the base materials by the molten solder. Also, interdiffusion of the base metals and zinc solder will take place as long as the assembly is at elevated temperature. This poses a serious problem if a brittle intermetallic compound is formed at the base metal-solder interface (Fig. 8). Aluminum does not form such compounds with zinc, but copper, iron and some other metals do. These brittle layers reduce the strength of joints subjected to impact or peeling by an amount proportional to their thickness. Consequently, to minimize compound formation, heating should be discontinued as soon as the solder runs into the joint. Satisfactory dissimilar-metal joints between aluminum and copper, steel or silver may have intermetallic layers up to 0.0003 in. thick.

Dip Soldering

Dip soldering is suitable for joining cellular heat exchangers and similar assemblies having a large number of capillary joints (Fig. 9). With proper procedures, a vertical capillary pull of more than an inch can be expected. This process is recommended only for aluminum-to-aluminum joints. Dip soldering dissimilar metals such as copper to aluminum in a zinc solder generally results in rapid solution of the aluminum portion of the assembly.

In dip soldering, the assembly is degreased, then placed in a suitable jig and preheated. As soon as the assembly reaches the desired temperature, the first face to be soldered is dipped into a bath of molten flux. Capillary action draws the flux into the joint and allows it to clean the surfaces. The face is then dipped into molten solder which is readily pulled into the capillary spaces to form the required joints. If other faces are to be soldered, the operation is repeated. Flux remaining on the piece must be removed.

Temperature control is particularly important in dip soldering. The flux temperature should be the minimum giving adequate action, and the solder should be at a temperature slightly above its liquidus temperature. It is desirable for the flux temperature to be slightly higher than that of the solder. The preheating temperature should be at least as high as the flux temperature. If the preheating temperature is too low, the flux will freeze in the capillaries. If the assembly loses too much heat between the flux dip and the solder dip, excess solder will be retained in the joint areas and there will be a danger of plugging small holes in the assembly. On the other hand, if the temperature of the flux or solder is too high or if the time in the solder is too long, "chewing" (solution of the aluminum) will be more severe.

Resistance Soldering

Resistance soldering is a rapid and simple method for joining aluminum. Equipment and procedures are similar to those employed in commercial resistance brazing. Such equipment gives satisfactory control of soldering conditions. Applications include joining of light-gage fins to heavier material, joining of relatively thick aluminum electrical conductors, and attaching silver to aluminum carriers for electrical contactors.

In making joints between light-gage fins and heavier material, a high-zinc-chloride flux without added solder is applied as a slurry. The heavy piece is clamped between the two electrodes. When a large current is passed, the heat generated in the heavy piece causes the flux to react and deposit the zinc needed to make the joints. The only requirement is that the fins be in sufficiently good thermal contact with the heavy piece that enough heat is supplied to them to react the flux. After soldering, the flux residues are removed.

In making a lap joint, the pieces are assembled with solder and flux in place. The assembly is clamped between two carbon electrodes and large current is passed between them. When the joint reaches temperature, the flux reacts and the solder melts. The clamping pressure distributes the solder throughout the lap. Flux removal completes the procedure.

The design of lap joints must be such that the gases produced by the flux can escape. Otherwise, the joint will contain porosity and entrapped flux. Flux and gas entrapment can be avoided by knurling or otherwise roughing the surfaces to be bonded. Alternatively, a wire filler or some similar roughened shape of filler alloy will allow the gas to escape from the joint before the filler alloy melts and collapses.

Resistance to Corrosion

Resistance to corrosion is normally the factor that determines whether soldering can be successful for a specific application. The effect of solder, flux and base-alloy composition, joint design and environment on the resistance to corrosion of soldered aluminum joints,[3] and the mechanism of corrosion[3, 5] of such joints have been covered in the literature. However, the aspects that are peculiar to zinc-soldered joints should be emphasized.

The solders for aluminum that are most resistant to corrosion are pure zinc and zinc solders containing small

additions of aluminum, silver, nickel, copper or similar metals having melting points higher than zinc. In severe corrosive environments, these solders are subject to a relatively slow surface attack in contrast to the extremely rapid interfacial attack that is prevalent in soft-soldered aluminum joints.

Additions of low-melting metals such as lead, tin, cadmium and bismuth to zinc-base solders would be desirable to lower the melting point and increase the fluidity of the solders. However, their addition produces a marked decrease in the resistance to corrosion of the joints. The presence of such elements, either as alloying additions or as impurities, should therefore be avoided in zinc solders.

For the same reason, fluxes used in zinc soldering should not contain chlorides of these low-melting metals since they will be deposited in the joint. Even a fraction of a percent of these chlorides can seriously reduce the life of the soldered joint.

It is essential that all residues from chloride fluxes be removed from joints. Any moisture in the environment is readily picked up by these residues and electrochemical corrosion is initiated. To obtain the maximum life from zinc soldered joints, the desirability of a cleaning operation subsequent to soldering is again emphasized.

The best joints are those not easily penetrated or pried apart by products of corrosion. Thus, in a socketed-tube joint, the corrosion of the solder will be slowed to a negligible rate by the accumulation of corrosion products in a narrow passageway that cannot be pried apart. In a simple lap joint, the corrosion products will pry the joint apart and increase the rate of corrosion. Soldered joints using zinc-base solders corrode preferentially at the solder fillets. It is desirable to design joints as line contact joints or as taper fits, instead of parallel laps, to decrease porosity and flux entrapment.

Exposure environment is perhaps the most important factor affecting resistance to corrosion. Joints made with zinc solders last many years in ordinary atmospheres and are in good condition after ten years of exposure to marine conditions. Zinc-soldered joints exhibit good resistance to external corrosive conditions similar to those encountered in air-conditioning equipment. Zinc-soldered joints also appear to be compatible with most common freon-type refrigerants if the freons are dried to a moisture level acceptable in commercial practice. A hot, humid environment is, however, bad for zinc-soldered joints. Regardless of the environment, the resistance to corrosion of soldered joints can be improved by a protective coating. This is particularly true in the case of transition joints between aluminum and copper, steel or other materials.

Mechanical Properties

The strength of a zinc-soldered joint is greater than that of a soft-soldered joint. The tensile strengths of zinc solders will be in the range of 15,000 to 40,000 psi, depending on the composition. Socketed joints designed to fail through the solder gave a shear strength of 18,000 psi for a zinc-aluminum solder, a strength greater than the shear or tensile strength of many of the common aluminum alloys.

Since the strengths of zinc solders are good and since the bond is metallurgically sound, it is not surprising that socketed-tube joints of aluminum to itself or to dissimilar metals fail in the tube wall rather than the joint when tested hydrostatically or in tension. This is true even after three months of exposure to accelerated environments of $3\frac{1}{2}\%$ sodium chloride intermittent spray or 100% relative humidity at 125° F. Further evidence of the strength of zinc solders is that in finned assemblies the joints are invariably stronger than the fin material.

Although zinc-soldered joints in aluminum are very ductile, joints between aluminum and copper or copper alloys have low stripping strengths because of the brittle intermetallic phase between the copper and the zinc-base solder. For the same reason, lap joints between aluminum and copper have poor resistance to impact. Similar intermetallic compounds form between zinc solder and some other materials such as steel, although the loss of strength is less pronounced than in aluminum-to-copper joints.

Summary

Zinc soldering is an excellent process for joining aluminum to itself and to many dissimilar metals. It is an easy and low-cost method for making strong, corrosion-resistant joints at intermediate temperatures. It can be employed in furnace, torch, resistance and molten metal dip soldering processes for making a variety of assemblies.

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SILVER BRAZING LAP JOINTS IN STAINLESS-STEEL TUBING

Paper by G. H. Bohn was published in the September 1956 issue of The Welding Journal, 35, 884–889.

DISCUSSION BY K. M. WEIGERT

In his paper the author has brought up a subject that has been discussed for a long time, but not yet clarified sufficiently to enter the AWS-ASTM Specifications, namely, the strength of brazed joints.

The author mentions the influence of the clearance on joint shear strength. In the course of such investigations[1, 2] it has been brought out that the shear strength of brazed joints is at its optimum at about 0.005 in. approaching a lower value for wider gaps. The question arises why the clearance of 0.015 in. was chosen where three times the amount of brazing alloys was used at somewhat lower strength. In a private correspondence the author gave a correction for his Fig. 1–3 showing that the OD of the inside tube was the same as the ID of the outside tube. The clearance was obtained by drilling[2] the outside tube to a depth predetermined by the inside tube thickness "T" (usually between 2–3 "T") (see Fig. 12 of Author's Closure). Filler-metal shear-strength data had been tabulated for various commercial silver solders[3] based a special jig design for determining shear strength of brazed joints.[4] Subsequently, this data was submitted by Bela Ronay to the members of the AWS Committee on Brazing and Soldering for discussion of tentative specifications of filler metal joint strength.

The volume V of the brazing alloy used in each joint can be calculated from the given dimensions:

$$V = \frac{1.052 + 1.083}{2} \times 3.14 \times 0.0155 \times 0.345 = 0.0179 \text{ in.}^3$$

K. M. Weigert is Research Metallurgist, Curtiss-Wright Corp., Quehanna, Pa.

The 0.02 in.^{3} consume approximately 0.1 oz t of solder or 6.7 cents per joint for BAg-3 solder. By using a clearance of 0.005 in., as generally recommended, the cost per joint could be reduced to 2.2 cents per joint.

Brazing Temperature of the B Ag-3 Alloy

Details on the phase fields of this complicated alloy have not yet been published. However, several users have confirmed the findings that a brazing temperature of at least 1300° F is required for a strong and ductile joint. The temperature of 1270° F is an intermediate liquation temperature (not the true liquidus) but small amounts of a copper-nickel phase become completely liquid over 1400° F. In a previous discussion[5] it has been brought out that the crevice corrosion effect referred to by the author can be explained by infiltration of low melting silver-bearing phases below the stress-relieving temperature. The effect is only a serious problem in cold-rolled stock of more than $^1/_4$ in. diam. The relatively thin tubing used by the author could be preheated to about 1300° F before applying the solder. Cadmium-free, nickel-bearing solders, as, e.g., B Ag-4, have been designed for such high-melting temperatures where stress relieving has already taken place to a certain degree.

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AUTHOR'S CLOSURE

(1) The question of why a clearance of 0.015 in. and not 0.005 in. on a side was used, is explained in the paper regarding design Figs. 9 and 10.[1] However, the following further explanation is given. The tests were made based on the maximum clearance that can be expected in designs when using stainless-steel tubing or pipe as purchased. According to two ASTM *tubing* specifications,[2] the permissible mill OD tolerance on tubes 3 to 4 in. inclusive, is plus or minus 0.015 in. and on tubes over 4 in., plus 0.015 in., minus 0.025 in. Using the

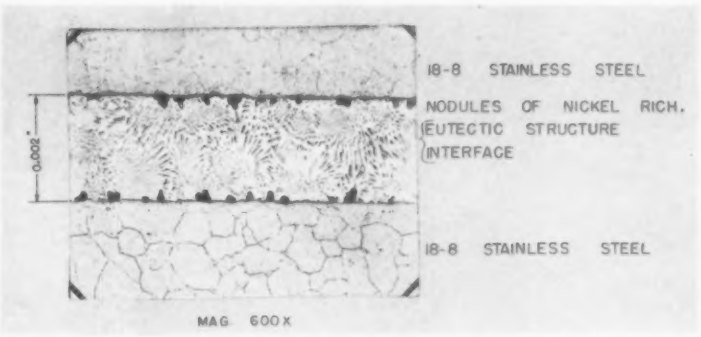

Fig. 11 Silver-brazed joint for stainless steel made with B-260 - BAg-3 silver solder

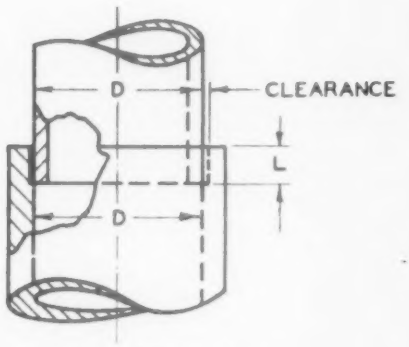

Fig. 12 Details of test joint

design procedure explained for Fig. 10,[1] the maximum clearance would be 0.015 in. and 0.020 in. respectively for such sizes of tubing. According to two ASTM *pipe* specifications,[3] the permissible OD tolerance on pipes $^1/_8$ to $1^1/_2$ in. is plus 0.015 in., minus 0.031 in. and on larger sizes even greater. On 5S and 10S thicknesses of stainless-steel pipe,[3] the wall thickness is too thin to machine to closer tolerances, so you must use the pipe as made by the mill. The tests for the paper[1] were therefore made with 0.015 and 0.017 in. clearances.

According to H. R. Brooker,[4] the brazing-alloy tensile strength is a constant of 60,000 psi from approximately 0.008-in. to 0.020-in. clearance. The brazing strength is a maximum of 70,000 psi with less clearance. Since brazing shear strength is probably a direct ratio of the tensile strength, it would appear that clearances up to 0.020 in. could be used where it is necessary.

Dr. Weigert[2] mentions the advantage of flowing the brazing alloy across the end of the tube for such constructions as Figs. 3 and 4.[1] This does have the effect of adding additional strength to the joint and is an excellent idea where it can be done. The trouble on a great many joint designs is to insure that the brazing alloy goes completely across the end; it has been found that the brazing alloy icicles tend to form on the inside, break off and get jammed in valves, controls, etc.

When joining heavy stainless-steel tubing to a stainless-steel connection, welding is generally the best procedure. This welding can be butt or a filleted socket joint. On the latter type of design, welding a wall thickness below $^1/_{16}$ in. might cause puncturing at the weld so silver brazing the socket joint is better. On tube wall thicknesses less than $^1/_{16}$ in., the author's recommended minimum lap from a practical viewpoint is $^3/_{16}$ in., so, in such cases, the lap is actually more than needed—the additional strength gained by brazing the ends is not needed.

Photomicrograph

After the paper was published, the author received a photomicrograph from Handy and Harman of a silver-brazed stainless-steel joint made with the BAg-3 alloy. C. H. Chatfield, senior metallurgist, gives the following explanation of this photomicrograph:

"This is a cross section through a lap joint which was torch brazed. The magnification is 600 × so that the actual thickness of the brazing alloy in the joint is about 0.002 in.

The picture shows that there is no measurable penetration of the brazing alloy into the steel. The dark nodules along the face of the joint are the nickel-rich constituent in the BAg-3 separating out on the surface of the steel. The balance of the brazing alloy shows a typical eutectic structure."

This is shown as Fig. 11 herewith.

Clarification

It has been brought to the author's attention that Figs. 1 and 2[1] indicate that the silver solder during the test could have been run down the side and across the ends. The test joints were made so this could not happen. The solid half of the test specimens was first bored to exactly the same diameter as the OD of the tube. Then the ends for the lap joints were machined larger by 2 x the desired clearance. This is shown by Fig. 12 herewith.

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VIADUCT SETS WELDED-GIRDER RECORD

BY EDWARD J. RAMER

Setting a new span record for all-welded plate-girder construction in the U. S., a New York Thruway viaduct spans 234 ft across the Erie Railroad near Suffern, N. Y. Believed also to set a world mark for girders of the single-web type, the long span was necessary because of track congestion below.

The viaduct is actually two 3-lane bridges side by side. Six spans make up its total length. Each span contains 14 girders, spaced 8 ft 4 in. center-to-center.

The record-setting girders are made up of 50-ft cantilevers and a 134-ft suspended member (Fig. 5). The cantilevers extend from adjoining 125-ft anchor spans.

The remaining three spans—97 1/2 ft at the west end of the viaduct, 117 1/2 ft and 100 ft at the east end—are simply supported.

Besides traffic lanes 12, 13 and 12 ft wide, each bridge carries two 6-ft wide strips for maintenance vehicles and disabled cars and two 2 1/2-ft wide safety walks.

The previous span record of 200 ft for welded plate girders in this country was established in construction of a bridge across the San Jacinto River in Texas. European bridge builders, however, have used multiple-web construction for much longer spans. Welded box girders in the Pont Corneille, a Seine River crossing at Rouen, France, for example, span 328 ft.

The New York State Department of Public Works adopted the cantilever and suspended span for the viaduct as the cheapest design that would be shallow enough to clear the Erie tracks by 22 1/2 ft, as required by the railroad. Continuous girders were ruled out because of the skew and curvature of the crossing. The viaduct occurs in a curving stretch of the thruway, where the Hudson section of the super highway swings 90° from its north-south alignment to link up with the east-west direction of the Tappan Zee Bridge across the Hudson River. Cramped by topography and railroad operations in the vicinity, the bridge designers had to round the curve on a 2000-ft radius, a little tighter than the minimum standard of the thruway.

Fig. 1 Elevation showing completed structure of Suffern viaduct

Once the general type of structure was determined, comparative cost estimates dictated all-welded girders and composite construction. The 7 1/4-in. reinforced-concrete deck participates with the girders in carrying loads. Composite action between slab and girders is developed with spiral-bar shear connectors welded to

Fig. 2 Completed viaduct sports trim lines, due partly to horizontal web stiffeners used on outside girders. Girder depth is 4 ft, 8 in., increasing to 11 ft at the columns on each side of the tracks

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Fig. 3 Fabrication operations on some of the welded girders

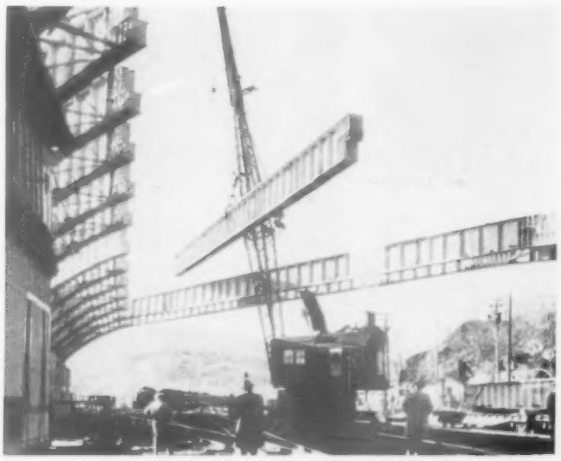

Fig. 5 The suspended girder being swung into place is one of 14 comprising the middle section of the record span. The supporting girders (arrow), cantilevered 50 ft from adjacent bays, complete the span

the top flanges of the girders. The structural slab is topped with a 4-in. concrete wearing surface.

Girder depth throughout most of the length of the bridge is 4 ft 8 in. (Figs. 1, 2 and 3). It is enlarged to 11 ft, however, at the columns for the 234-ft span, to resist large cantilever bending moments.

Web plates of the girders are $^3/_8$- and $^1/_2$-in. thick. Flanges range from $^3/_4$ in. in thickness, 18 to 24 in. in width. Webs are stiffened both sides with vertical plates, except on the exposed side of outer girders. Here, for better appearance, horizontal stiffeners were used.

Because of bridge curvature and to eliminate any possible torsion, a special support was devised for the suspended girders. Actually not a suspension at all, the connection is constructed so that the so-called suspended members are seated on the cantilevers. The bearing at one end is rocker-type at the other end, sliding type. Girder ends are notched out for the bearing assemblies, so that no break in girder elevation occurs at the connections.

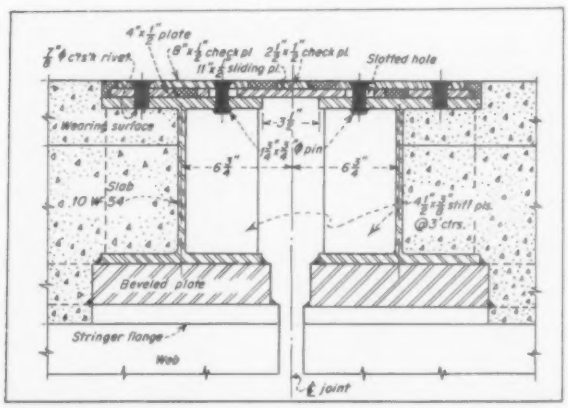

Fig. 4 Expansion joint is bridged, for roadway continuity, by a sliding steel plate. To prevent water from leaking to the railroad bed below, the joint is calked with rubberized asphalt

These girder connections and armored steel joints in the deck above are designed to permit the structure to expand longitudinally. While fulfilling this function, however, the deck joints are also required to prevent leakage of water to the railroad.

Bridging each of the two transverse expansion joints in the deck, an 11 x $^1/_2$-in. steel plate maintains continuity of the roadway. The plate is supported continuously along either side of the joint in a pocket or slot in which the plate is free to slide. The pocket is formed by an assembly of steel plates welded to a transverse header beam. The beam is welded in turn to the girders. The sliding joint, calked with rubberized asphalt, is waterproof (Fig. 4).

The viaduct was designed under American Association of State Highway Officials specifications for H20-S16 live loading. Welding design was based generally on the American Welding Society specifications for welded bridges. Electrodes with coverings of low-hydrogen type were used for all welding—shop and field. In general, the welds are fillet-type. But at critical spots in the special bearings a combination of butt and fillet welds was used.

Materials used in the bridge included 3100 tons of structural steel, 675 tons of bar reinforcement, 7300 cubic yards of concrete and 32,000 lin ft of piles.

Preliminary studies and designs and all contract plans, specifications and estimates were prepared in the Albany Office of the New York State Department of Public Works, under the direction of E. W. Wendell, deputy chief engineer in charge of bridges, grade separations and structures (since retired and succeeded by C. F. Blanchard). John W. Johnson is superintendent and Thomas F. FitzGerald, chief engineer of the department.

ALUMINUM-BRONZE OVERLAYS AND CAST BUSHINGS OPERATE CHEATHAM DAM GATES

BY WILLIAM J. FAUSER

Philips and Davies, Inc., of Kenton, Ohio, one of the major producers of equipment for flood control, power and irrigation since 1918, has installations all over the world.

This company has built six wheel-type gates to be installed in the Cheatham Dam near Dickson, Tenn. These gates were 18 ft 8 in. wide and 35 ft high. Each is equipped with 14 wheels which ride on a vertical track.

Since these wheels are operated in water and must give continuous, trouble-free operation, the axle-bearing area was overlaid with ECuAl-C electrodes using the metal-arc process and aluminum-bronze castings were selected for the bushings. These two materials form a corrosion-resistant, long-wearing bearing combination suitable for service under adverse conditions, which are normal for this type of equipment.

The bearing areas of the axles are first machined undersize on the diameter for depositing a $^{3}/_{16}$-in. thick overlay of ECuAl-C electrodes, as shown. The deposits are applied in two layers with $^{3}/_{16}$-in. diam ECuAl-C electrodes. The deposits are machined, bringing the axle to proper dimensions.

William J. Fauser is associated with Scott-Tarbell, Inc.
All Photos courtesy of Ampco Metal, Inc., Milwaukee, Wisc.

Fig. 2 Axle after machining showing dense, uniform, bearing area

Fig. 1 Welder applying ECuAl-C to axle bearing area

Fig. 3 View of completed wheel and axle assembly

PACKAGED MACHINE WELDING

Installation at tubing manufacturer's plant typifies tailor-made service of machine welding concept

BY J. H. BERRYMAN AND W. T. DAVIS

The manufacture of heat-treating equipment made of lightweight welded sheet alloys is the specialty of Pressed Steel Co., Wilkes-Barre, Pa.

This has called for a concentration of welding expertness to deal, as they do, in the entire range of alloys. The company is justly proud of its welding department, staffed by highly experienced welding engineers and operators. To assure welds as strong and corrosion-resistant as the base metal, a wide range of welding processes is used.

Naturally, new ways to improve welding techniques are constantly being sought. Recently, in evaluating the production methods on their all-sheet alloy radiant furnace tubes (Fig. 4), the manufacturer decided an improvement could be made by adopting more of the controls which machine welding makes possible. With as many as 96 of these gas-fired heating tubes used in one annealing furnace, perfection of welds is of utmost importance. So any change of welding methods required specialized planning.

As a result, machine specifications were developed from which the design and construction of the installation shown here were made. The outcome: a complete package—automatic gas-shielded metal-arc process equipment, fixtures and all controls tailored to the job to produce welds of the size, quality, type and speed required (Fig. 1).

In operation this automatic machine welding instal-

J. H. Berryman is Manager, Machine Welding Department and **W. T. Davis** is Process Engineer, Air Reduction Sales Co., New York, N. Y.

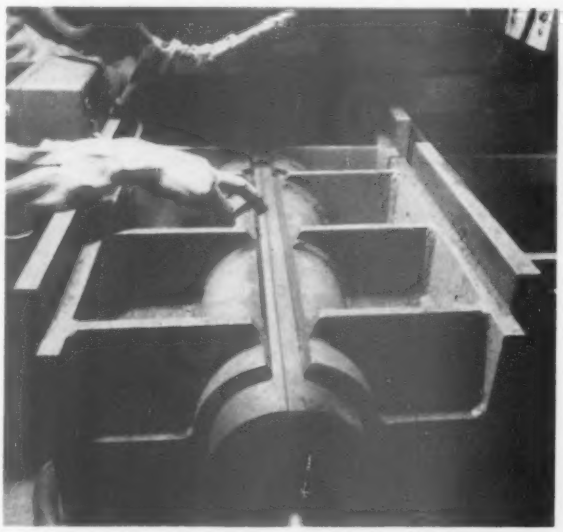

Fig. 2 The full penetration of gas-shielded metal-arc welding on flush butt joints eliminated bevelling on all $^{3}/_{16}$-in. and $^{1}/_{4}$-in. tubing

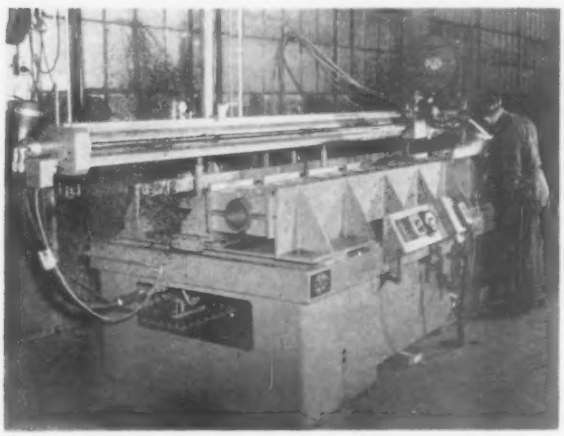

Fig. 1 Typical equipment for the welding of stainless-steel radiant tubing

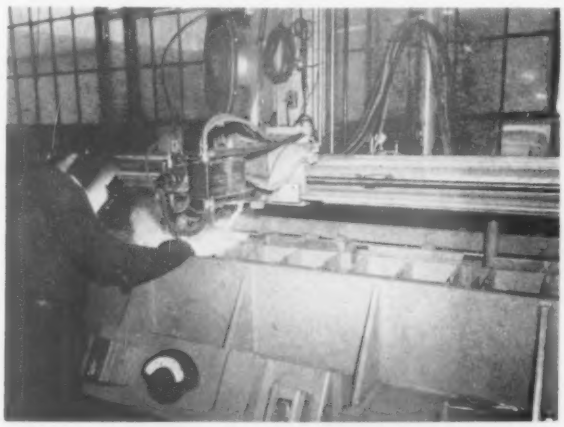

Fig. 3 Welding equipment in operation on $^{3}/_{16}$-in. thick tubing, $5^{3}/_{8}$-in. OD, welding speed 30 ipm

Fig. 4 Stainless-steel radiant tubing. Used in annealing furnaces, consistently high quality is a must

lation, handles 3 in. diam to 12¾ in. diam, austenitic type stainless-steel tubing in thicknesses from ⅛ to ¼ in., and welds at a speed of 30 to 60 ipm, using argon (plus oxygen additive) for shielding, and 1/16-in. stainless-steel wire.

In addition to a greatly increased rate of production, machine welding brought many other improvements to the fabrication of stainless tubing at Pressed Steel. For instance, because of the full penetration of gas-shielded metal-arc welding on flush butt joints, champfering of seams is eliminated on all 3/16-in. and ¼-in. wall tubing (Figs. 2 and 3). Formerly a complete bevel was necessary.

Moreover, when manual welded, the tubing had to be tack-welded first. This is unnecessary with the machine process because the fixture provides close fitup for the full seam which is completed in one continuous pass.

In machine welding installations such as previously described, all controls intended to produce welds of a predetermined type, size, quality and speed are established beforehand by welding engineers and the operator can concentrate on operating the machine. The procedure is tailored to suit the specific job which is wrapped up in one package—process, fixtures, jigs and engineering. This approach quickly and efficiently meets the needs of high-production industries where machine welding installations are increasingly becoming the order of the day.

INERT-GAS TUNGSTEN-ARC WELDS REACH OUTER SPACE

To learn the secrets of outer space, an earth satellite—fabricated with inert-gas tungsten-arc welding—will soon circle the earth at a rate of 18,000 mph.

Brooks and Perkins, Inc., Detroit, Mich., is producing several of the 5½-lb, 20-in. diam spheres for Project Vanguard—an Army, Navy, Air Force project under Navy management. Purpose of the project is to launch one or more satellites during the Geophysical Year of July 1957, to December 1958.

The satellite will be rocketed into space in an attempt to shatter the ionosphere, a layer of electrically-charged air surrounding the earth between 50 and 250 miles from its surface. Instruments inside the sphere will record geophysical and solar research information that is needed before man himself can conquer outer space.

The shell of the satellite consists of an upper and lower hemisphere and an inner ring. The hemispheres are deep-drawn from 0.090-in. thick flat-stock magnesium sheet, composed of 96% magnesium, 3% aluminum, and 1% zinc.

After they're deep-drawn, the hemispheres are spun on a lathe to give them an exact contour. Then the inner ring, which has also been spun to shape, is inert-gas tungsten-arc welded to the interior curvature of the lower hemisphere (Fig. 1).

Fig. 1 An operator tungsten-arc welds the contoured ring into the lower hemisphere, creating an air-tight pressure chamber inside the satellite. This chamber is then leak-tested under 25-psi hydrostatic pressure to check joint soundness

By welding the concave ring into the lower hemisphere, a special air-tight pressure chamber is created

Based on a story by the Linde Co., New York, N. Y.

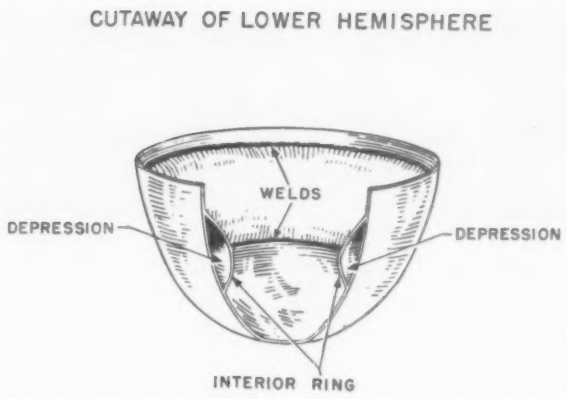

Fig. 2 This cutaway drawing shows the lower hemisphere after the concave inner ring is welded in place. The depression in the ring forms the pressure chamber which will be used to measure the size and speed of space particles

in the satellite. Registering variations in relative pressure, this chamber will record the size and speed of space particles which may hit the satellite (Fig. 2).

Each hemisphere is machined, gradually reducing its thickness from 0.090 in. to 0.050 in. at the top and 0.030 in. at the bottom. This gives the assembled shell greater strength at the ends to withstand stresses during launching.

The internal framework of the sphere, designed for carrying the electronic equipment, is tungsten-arc welded from magnesium tubing. This is the only process which can be used to efficiently fabricate the magnesium satellites.

Fig. 3 Here is the internal framework, held in a reverse position, as it is being assembled by tungsten-arc welding. The top plate (below) will suport an access door for checking instruments. The bottom tube (above) will connect to the third-stage rocket

Four antennae mounts are welded into the internal framework, serving as structural pieces to join the framework to the shell. Two additional framework components are tungsten-arc welded: (1) an access door ring, providing an opening into the assembled satellite for checking instruments before launching; and (2) an end ring, providing an opening for connecting the launching rockets (Fig. 3). All welded parts are stress-relieved to remove any harmful stresses developed during welding.

Tungsten-arc welding torches are used for all welding operations. Alternating current high frequency is used, at a current setting of about 100 amp, to insure maximum joint strength and density. Using magnesium filler rod, the operators weld at an average speed of about 6 ipm. Inert argon gas, at a flow of 20 cu ft per hr, protects the weld zone from atmospheric contamination.

The hemispheres are joined by watchmakers' screws which are so minute that they don't interfere with the surface of the sphere. To prevent damage to the mirror-smooth four microinch finish, human hands are not allowed to touch the satellite after it is machined and buffed.

Using an electromechanical process, the spheres are then goldplated. After delivery to the Naval Research Laboratory, the exterior surface of the satellite is given four additional coatings: (1) silicon monoxide, (2) vaporized chromium, (3) vaporized aluminum, and (4) a final coating of silicon monoxide.

A three-stage rocket, 72 ft long and weighing 11 tons, will launch the satellite on its mission. The first two stages will raise the sphere to an altitude of 300 miles and a speed of 9000 mph. Then the third stage will project the satellite into its orbit at a speed of 18,000 mph (Fig. 4).

At its most distant point, the satellite will be 1400 miles from the earth. It will be tracked by ten observation stations which will receive data radioed back to the earth by the instruments inside the sphere.

Fig. 4 These full-scale models show the interior and exterior of the earth satellite. The electronic equipment will record valuable geophysical and solar research data—as the sphere circles the earth at 18,000 mph

Society News

Chicago Site for Metal Show

Chicago will be the site on November 2nd through the 8th of the 2nd World Metallurgical Congress, sponsored by the American Society for Metals.

The ASM schedules 129 papers and discussions, 50 of which comprise the technical program; 42, the Atomic Energy Commission sessions on thorium, welding and metallography; 20 on seminars on metal characteristics, and 17 international panels presenting some 120 United States, Canadian and overseas metal scientists discussing metal problems having greatest current concern. Meetings are scheduled for the Palmer House and Hotel Sherman.

The Metals Division of the American Institute of Mining and Metallurgical Engineers sponsors 22 symposiums, seminars and papers. The Society for Nondestructive Testing, holding its Second International Conference in conjunction with the Metals Congress, is presenting 10 major sessions in three days. Both societies meet in the Morrison Hotel.

The science of welding will be represented in the special meetings organized by the Atomic Energy Commission internal group on welding during a morning session at the Palmer House on November 6th. Entitled "Welding of Stabilized 18-8 Stainless Steel," this particular session will be followed by an afternoon meeting devoted to the "Welding of Rare Metals."

As part of the group of international panel discussions at the Hotel Sherman, Group V—"Welding and Joining," will be comprised of the following discussions: "Ship Welding" on Monday morning, November 4th in the Crystal Room—D. P. Brown, president of the American Bureau of Shipping, moderator; "Electrodes" on Monday afternoon, November 4th in the Crystal Room—D. C. Smith, Harnischfeger Corp., moderator; and "Stress Relieving and Preheating" on Tuesday afternoon, November 5th in the Louis XVI Room—Leon Bibber, United States Steel Corp., moderator.

Other scientific panels will be devoted to steelmaking and refining, nonferrous refining, metal fabrication, heat treatment, inspection and testing, education and research, and metallurgical aspects of Atomic energy.

The Metal Show itself will be held in Chicago's International Amphitheatre where 450 exhibits will be displayed on 20,000 sq ft of floor space. The hours at the amphitheatre will be: Monday through Wednesday, November 4th to 6th—12 noon to 10:30 P.M. For Thursday and Friday, November 7th and 8th—10 A.M. to 6 P.M.

The Campbell Lecture will be held on November 6th at which time Dr. Earl R. Parker, Professor of Metallurgy, University of California at Berkeley, Calif., will present his paper, "Modern Concepts of Flow and Fracture."

New Supporting Company Member

A supporting company member enrollment application has been received from the Bentley Sales Co., 646 S. 29th St., Milwaukee 46, Wis. The enrollment became effective on August 1st.

Boeing Airplane Company Becomes Sustaining Member

The Boeing Airplane Co., Seattle, Wash., has recently joined the ranks of Sustaining Members of the AMERICAN WELDING SOCIETY.

Boeing is internationally famed for its B-17 Flying Fortresses and B-29 Strato-Fortresses, both heavy bomber mainstays of the U. S. Air Force during World War II; for the development of the jet powered B-47, a medium bomber, and the B-52, a heavy bomber which is presently the chief defensive weapon of the U. S. Air Force.

Boeing currently is using jet powered engines for all of its production type airplanes—the first aircraft company to do so—and has attracted world-wide attention by its famous Boeing 707 commercial jet transport, the first to be produced by an American aircraft company.

I. M. Crawford, Supervisor, Engineering Metals Unit—Welding Group, has been appointed Sustaining Member representative.

AWS DIRECTORS-AT-LARGE

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Junior Past-President	F. L. Plummer	*Junior Past-President*	J. J. Chyle

THINGS YOU SHOULD KNOW

(That Happened in August)

• Voting on the proposed bylaw amendments, previously approved by your Board of Directors, officially closed on August 15th. The Tellers checked the ballots the following day and, as announced in the September JOURNAL, reported that all amendments had been approved by the membership. A total of 2649 ballots were received and only the amendments covering initiation fee, change of grade of membership, amount of dues, reinstatement fee and refund to sections received a significant number of negative votes. Several members submitted comments and suggestions which will be reviewed by members of the Constitution and Bylaws Committee. The amendments became effective immediately.

• At the Annual Meeting in Philadelphia last April, a special session, organized by Second Vice-President C. I. MacGuffie, was devoted to consideration of a welding information program for the AMERICAN WELDING SOCIETY. At a later meeting, your Manufacturers Committee took action instructing its Sub-committee on Welding Information, of which Mr. MacGuffie is Chairman, to reproduce the information presented at this special meeting and to send it to interested companies, together with a request for funds to underwrite such a program which would include the establishing of a Welding Information Center at SOCIETY Headquarters. With adequate support from industry, this program can effectively and significantly increase knowledge about and use of welding and allied processes.

• Plans have been announced for a new United Engineering Center, a ten million dollar project, to be erected in New York City adjacent to the United Nations Building. Land for the new Center has already been purchased, and it is expected that a twenty-story tower, surrounded by lower structures, with complete library, meeting rooms, dining rooms and other facilities will be constructed. Your SOCIETY has been invited to occupy space in these buildings when they are completed, probably in 1960. Past-President J. H. Humberstone held a meeting of the Headquarters Housing Committee on September 16th to consider whether AWS should reserve space in this new Center, or whether we should establish our own individual headquarters in Manhattan, in the New York metropolitan area outside of Manhattan, or at some other location, possibly in the Midwest. This committee may submit recommendations to your Board of Directors at their meeting in Chicago November 7th.

• During July, the International Institute of Welding held its annual meeting at Essen, Germany, with a registration of 823 people representing 22 countries and including 51 from the United States. At the same time and place, a huge two-weeks long welding exposition was held. The exhibits filled ten buildings and also included a number constructed outside. Several foreign visitors have called at AWS

PLUMMER ATTENDS DISTRICT 9 MEETING

National Secretary Fred L. Plummer pictured with District Director P. V. Pennybacker at the Section Officers Conference for District 9 held on June 27–28, at the Captain Shreve Hotel, Shreveport, Louisiana. Mr. Plummer provided the meeting with news items concerning National Headquarters activities.

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Headquarters after attending these events.

• On August 5th, R. M. Gooderham, Manager of Canadian Welding Bureau, visited your Secretary to report on the Essen meetings and to discuss relationships among our SOCIETY, the Canadian Welding Society and the CWB. On August 8th, W. A. Bayly, Secretary of the Australian Welding Institute, spent the day at our Headquarters reporting on these same meetings and discussing welding activities in Australia. Several representatives of the Japan Welding Society have also reported activities in Europe and in Japan to your Secretary. Welding Research Council Director W. Spraragen and our Technical Activities Committee Chairman Art Kugler have given more detailed reports on the IIW meetings and the Essen Welding Exposition. The 1958 meeting of IIW will be held in Vienna, June 30th to July 5th.

• C. E. Jackson, Chairman of the AWS Educational Activities Committee, has reported that preliminary outlines for educational courses are available for Section use in the following fields: Welding Metallurgy, Thermal Cutting of Metals, and Resistance Welding Theory and Practice. This is part of a program which includes preparation of a complete set of outlines and texts for educational courses in colleges, vocational schools, apprentice training and for use of Sections. One of the subcommittees of this group, with Butch Sosnin as Chairman, recently cooperated in planning a conference on welding equipment and procedures for apprentice training teachers in the piping field. The conference was held at Purdue University. Director C. M. Styler has recently called our attention to and established a contact with a similar activity in the structural field.

• Esposition Manager R. Kenworthy has distributed a small brochure giving a breakdown of the record-breaking attendance at the Philadelphia Welding Exposition. Also, at the beginning of September, he mailed floor plans and other information covering the St. Louis Welding Exposition to be held next April. Response to date indicates that this will be another "not-to-be-missed" show and meeting.

• When you read this, President Sander will have completed a two-weeks trip which began on September 15th and which was devoted almost exclusively to AWS activities. These will include meetings of your Headquarters Housing Committee, National Papers Committee, Technical Council, NWSA and PVRC in New York; the Second New England Conference on Welding in Boston; a meeting with representatives of the Canadian Welding Society in Buffalo; and meetings with the Houston Section and its four Divisions at Corpus Christi, Galveston, Beaumont and Austin.

• Dr. C. G. Keel, Director of the Swiss Welding Association, will visit the United States this fall and has generously agreed to speak before the Los Angeles Section on October 3rd, the San Francisco Section on October 7th, the Hartford Section on October 15th and the Long Island Section on October 17th. Dr. Keel will discuss "High Quality Welding Operations in Europe."

Fred L. Plummer

EMPLOYMENT SERVICE BULLETIN

Services Available

A-697. Position in either industrial management, or in sales or sales management desired by mature man, age 46, capable, personable, married. Specialized background in fields of welding, brazing, soldering alloys, fluxes, etc. for joining most metals. Hydraulic load lifting equipment, for materials handling applications, industrial, construction and automotive service fields. Also special alloy steels used in tool and maintenance applications. Traveled extensively in the past. Developed leading accounts, etc. Free to travel. Willing to relocate. Prefer eastern seaboard residence.

Positions Vacant

Excellent opportunity for young engineer to join national staff of American Welding Society in New York City. Recent promotion creates vacancy for assistant to technical secretary. Responsibilities to include representation on technical committees, research on technical data, editing of standards, answering technical inquiries from industry. Applicant must have degree in engineering, with at least three years experience, preferably in welding or allied fields. Salary commensurate with qualifications and experience. Send résumés to Technical Secretary, 33 W. 39th St., New York 18, N. Y. All replies will be held in confidence.

•

Civil Service Openings

The U. S. Civil Service Commission has revised and reissued the announcement of the currently open examination for engineer. This new announcement incorporates examinations for various specialized branches of engineering which were formerly publicized under separate announcements. The engineering positions to be filled are in various fields of work and pay from $4480 to $11,610 a year. They are located in various Federal agencies in Washington, D. C., throughout the United States, and in foreign countries.

To qualify for these positions, applicants must show appropriate education or experience in engineering.

For further information, including instructions on where to send applications, consult civil service examination announcement No. 112 B. Information on examinations and application forms may be obtained from most post offices or from the U. S. Civil Service Commission, Washington 25, D. C.

METALLURGISTS

Positions offering unusual professional growth opportunities with expanding Atomic Energy Division of long established manufacturer of power generating equipment. Minimum requirements—degree plus experience in practical metallurgy and fabrication of carbon and stainless steels. Knowledge of fuel element fabrication and/or other metallurgical and fabricational applications peculiar to atomic power generation desirable but not essential. Send resume and salary requirements to:

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Schenectady 5, N. Y.

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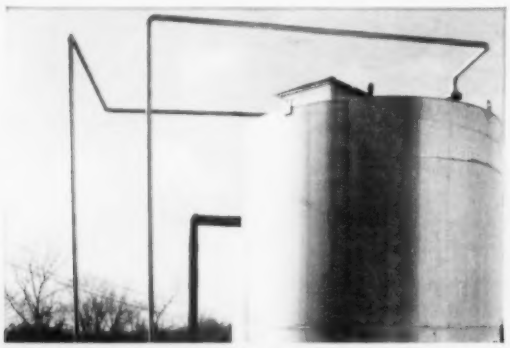

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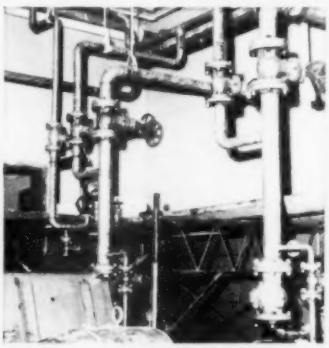

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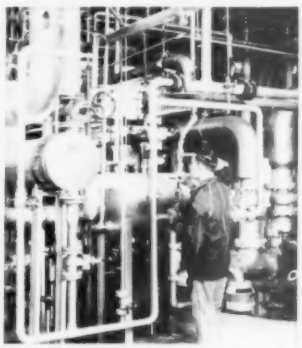

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EAC DOINGS

Visual Aids

by Richard C. Wiley

From earliest times pictures have been one of the most eloquent and one of the most easily understood forms of communication. Few of us realize, however, how deeply they have crept into our daily lives—so deeply that we would lead a very colorless existence without them.

Some of our earliest recollections are our picture books. Our reading preferences when we grew up made the picture magazine an instant success. Public demand for movies and television is too obvious to enlarge upon. Everywhere we are greeted with pictures. A picture tells us what to drink, what to wear, what to do with our money, and where to vacation. Our desires can be stimulated more rapidly by pictures than by any other means.

This visual technique is used today in all spheres of activity: education, entertainment, training and selling, to mention but a few. One of the most successful visual means of telling a story has been with motion pictures.

Education in Welding

Welding engineering knowledge is confined to relatively few, compared to the vast numbers who possess a working knowledge, for example, of electrical or mechanical engineering. The general public knows little about the many welding processes. Apart from the fact that metals are joined, the public is quite indifferent as to the method used.

This indifference, or lack of knowledge, is probably the direct cause for the scarcity of welding engineers, the dearth of welding technicians and the lack of efficient welders.

We need more widespread welding education on all levels and we need more interest in welding. We have got to tell the world. We have got to tell our story, to tell that welding is the prop which holds up our way of life. We have got to show how our children's future is dependent upon our ability to join metals. It is to stimulate this interest that a film on welding is proposed.

Type of Motion Picture

In the production of any film on education it is necessary to determine certain facts and objectives:

1. Audience
   a. age group
   b. standard of education
2. Engineering level
   a. graduate engineer
   b. technician
   c. welder
3. Student level
4. General public

When the audience has been determined it will be comparatively simple to decide upon the subject matter and story line for the film. If the film is directed to graduate engineers, it will be of a technical nature. If it is to be seen by students, it should emphasize the opportunities in the welding industry with a view to influencing them in the choice of a career.

The success of any such motion picture depends upon its selectivity. If it is aimed at too wide an audience, it will fail in its chief objective. It may entertain and interest but it will not spearpoint the interest sufficiently to convince a section of the audience to take the desired action.

If we want more students to study welding, we will have to produce a film which shows the opportunities in the welding industry. We have got to make them *want* to learn more about welding.

If our needs are for graduate welding engineers, we may have to slant our film in another direction—to educators to expose the need for facilities which are lacking in our educational system at the moment. Whatever slant we use, our objective remains the same—to stimulate action.

Distribution

The demand for educational motion pictures is extremely widespread. Such films are requested by fraternal societies, non-profit organizations, technical societies and associations, TV studios and networks, vocational schools, engineering schools and colleges and even by the U. S. Government.

The welding industry itself produces some excellent motion pictures. Photographically, they compare favorably with the best. Technically, they are probably superior to most films produced for entertainment. They have the advantage of having been supervised and checked by experts in the process or field covered by the film. Films are available covering practically every facet of welding.

These motion pictures are used very extensively by AWS sections as an extra attraction at their monthly meetings. Often when a speaker requires a motion picture to illustrate a talk, he can check the Film Directory for a suitable film and place an order sufficiently in advance of his meeting to ensure delivery.

Film Directory

Each year AWS Headquarters produces a Film Directory. In it are listed the films pertaining to welding together with particulars regarding each film. A typical listing would be:

Resistance Welding

Resistance Welding Stainless Steel: 16 mm., sound, color, 21 min.

Available: Name of Company
Address

A limited number of these directories is printed and one copy is mailed to each AWS chairman and secretary. The Program Chairman of a section thus is able to advise speakers upon suitable films to illustrate talks.

The Visual Aids Committee has been assigned the work of obtaining new material for this Directory and bringing it up-to-date.

Schools

Schools have become very motion-picture-minded. In one school where two projectors are available, the projectors are kept going almost continuously, so great is the demand.

If a directory specializing in a single subject, such as welding, were made available to schools, it would be invaluable. It would make them aware of the great variety of films produced on the subject of welding. It would save them having to hunt through large volumes in search of a specific subject. The selection of programs would be simplified and a service would be provided which is not available at present.

The production of a motion picture such as visualized would benefit the welding industry as a whole. It would not sell products or services. It might not produce personnel in the immediate future—but as a long-range program it would benefit manufacturer and user alike. The manufacturer would gain an increased demand for his products because there would be more welding engineers to specify welding and more welders to cope with the increased work.

The need for scientists and engineers is urgent and each year the need becomes greater. Producing the type of film we need will be costly. An inadequate supply of engineers could be more than costly, it could be disastrous.

Richard C. Wiley is Head of the Welding Department at California State Polytechnic College, San Luis Obispo, Calif. and chairman of EAC committee on Visual Aids.

Section News and Events

as reported to Catherine O'Leary

PANEL MEETINGS

Cleveland, Ohio—At a recent meeting of the *Cleveland* Section's Technical Program Committee, more emphasis was placed on the panel type meeting due to the tremendous success of last year's meeting.

The program formulated for the 1957–58 meetings will include two similar meetings; the first to be held October 9th, entitled, "Which is Better? AC or DC," with Jerry Hinkel of the Lincoln Electric Co., serving as moderator of the panel. The second panel type meeting will be held on March 12th, and will concern, "Design for Automatic Welding," with James Howard of the Lewis Welding and Engineering Co., as technical chairman for the evening.

Starting with the October meeting, all meetings will be held on the second Wednesday of each month; the last meeting on May 9, 1958 will be the 19th Annual Symposium. All meetings will be held at the Manger Hotel, with the social hour at 6:00 P.M., dinner at 6:30 P.M., and the meetings starting promptly at 8:00 P.M.

ELECTION OF OFFICERS

Saginaw, Mich.—The *Saginaw Valley* Section announces the election of the following officers for the 1957–58 season: Chairman, W. F. Williams, Buick Motors Division; 1st Vice-Chairman, Paul Klain, the Dow Chemical Co.; 2nd Vice-Chairman, J. P. Thorne, National Electric Welding Machines Co.; Secretary, Milan Wagner, Saginaw Welding Supply Co.; and Treasurer, George Case, Semet-Solvay.

WELDING PLASTICS

Miami, Fla.—Frank D. Miller of Southeast Distributing Co., was the guest speaker at the August 21st meeting of the *South Florida* Section. Mr. Miller's subject was "Welding of Polyvinyl Chloride Fittings."

In his introductory remarks, Mr. Miller pointed out that the use of plastics in corrosive atmospheres was increasing at a terrific rate due to relative ease and simplicity with which they can be formed and welded.

With the current industrial expansion in the South, and in particular in Florida, a large market has developed for plastic materials in the form of tank linings, duct work and piping for both fluids and electrical work.

Mr. Miller discussed the various methods of welding plastics and displayed pipe fitting fabrications. Compared to metallic fabricating, the fusion welding of plastics is relatively simple and the equipment necessary very minor. Since the heating medium is a hot gas, it is possible to repair leaks or damaged piping without shutdown because no flame or arc is used and an inert gas can be used, eliminating explosive conditions.

Mr. Miller then demonstrated the process and invited the members to try their hand.

The meeting was most instructive and enjoyed by all.

AT MIAMI MEETING

Frank D. Miller demonstrating the welding of plastics at the August 21st meeting of the South Florida Section

SECTION MEETING CALENDAR

NOVEMBER 1

PHILADELPHIA Section. 7:45 P.M. Engineers Club, Philadelphia, Pa. Panel Discussion: "Hard Surfacing."

NORTH CENTRAL OHIO Section. Bucyrus, Ohio. "Design of Welded Water Tanks," Perry Arnold, Chicago Bridge & Iron Co.

NOVEMBER 11

NORTHWEST Section. Elks Club, Minneapolis, Minn. Happy Half Hour 6:00 to 6:30 P.M. Dinner 6:30 P.M. "Structural Welding," LaMotte Grover, Air Reduction.

NOVEMBER 12

NEW YORK Section. Victor's Restaurant, 1 E. 35 St., N.Y.C. Get-together 5:30 P.M. Dinner 6:00 P.M. Program 7:00 P.M. "Power Sources," Harry Bichsel, Westinghouse Corporation.

NOVEMBER 13

CLEVELAND Section. Manger Hotel, Cleveland, Ohio. Social hour 6:00 P.M. Dinner 6:30 P.M. Meeting 8.00 P.M. "Iron Powder Electrodes."

NOVEMBER 18

PHILADELPHIA Section. Engineers Club. 8:00 P.M. "Construction Problems in Development of Guided Missiles," Dr. W. R. Lucas, Army Ballistic Missile Agency.

NOVEMBER 19

TOLEDO Section. Maumee River Yacht Club, Toledo, Ohio. Dinner 6:30 P.M. Meeting 8:00 P.M. "Resistance Welding."

NOVEMBER 20

HOUSTON Section. Ben Milam Hotel, Houston, Texas. 6:00 P.M. "Tooling for Welding," Anthony K. Pandjiris, Pandjiris Weldment Co.

PEORIA Section. Mecca Supper Club, Farmington Road, Peoria, Ill. 6:30 P.M. Dinner speech 7:45 P.M. "Low-Hydrogen Welding," Dr. D. C. Smith, Harnischfeger Corp.

PITTSBURGH Section. 8:00 P.M. Auditorium of Mellon Institute of Industrial Research (Oakland) Pittsburgh, Pa. "Resistance Welding," F. A. Bodenheim, Jr., Federal Machine & Welder Co.

NOVEMBER 21

BRIDGEPORT Section. Bridgeport, Conn. "Structural Welding," Van Rensselaer P. Saxe, Engineer.

MICHIANA Section. South Bend, Indiana.

NOVEMBER 26

SAN ANTONIO Section. Dinner at Youngblood's 6:30 P.M. "General Survey of Coated Electrodes," Albert Smith, The McKay Co.

Editor's Note. Notices for January 1958 meetings must reach Journal office prior to November 1, so that they may be published in December Calendar. Give full information concerning time, place, topic and speaker for each meeting.

New Members

Effective August 1, 1957

MEMBERSHIP CLASSIFICATION

A—Sustaining Member B—Member C—Associate Member
D—Student Member E—Honorary Member F—Life Member

Total National Membership	
Sustaining Members	*175*
Members	*6,175*
Associate Members	*6,446*
Student Members	*158*
Honorary Members	*9*
Life Members	*15*
Total	*12,978*

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ALBUQUERQUE
Morrison, Grady O. (C)
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ARIZONA
Crocker, B. E. (C)

BATON ROUGE
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Guidry, H. J. (B)
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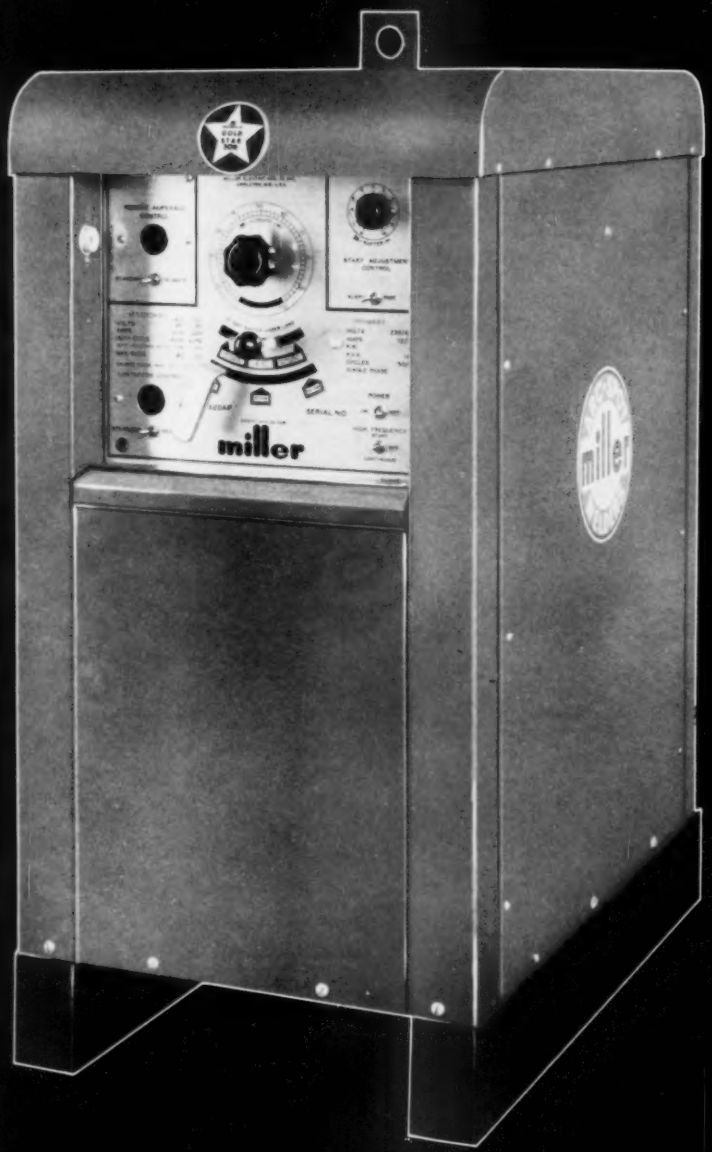

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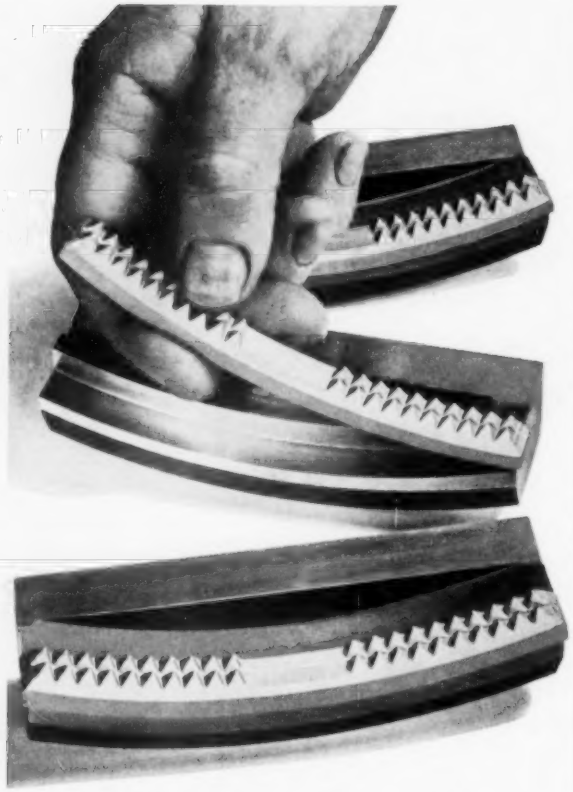

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LEHIGH VALLEY

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MILWAUKEE

Blackwell, Robert M. (C to B)

PUGET SOUND

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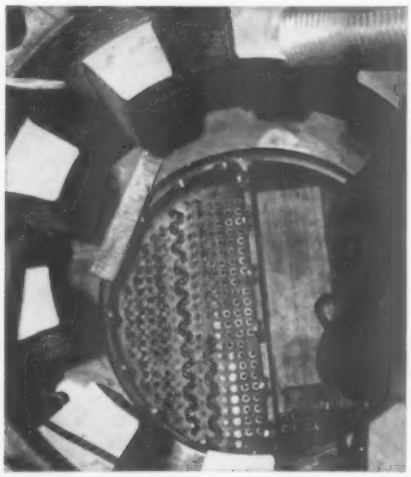

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,788,432—Continuous Fusion Furnace—Leslie Moles, Los Angeles, Calif., assignor to Hughes Aircraft Co., Culver City, Calif., a corporation of Delaware.

This novel furnace is adapted for forming fused P-N junctions upon the surface of monatomic semiconductor crystal bodies. A localized heating zone is provided in the apparatus and means continually pass a plurality of crystal bodies through the heating zone. A mass of solvent metal is deposited upon the crystal body when passing through the heating zone and other means maintain an inert atmosphere surrounding the semiconductor crystal bodies.

2,788,433—Stud Welding Gun—Thomas E. Shoup, Amherst, Roger W. Sholle, Lorain, and Lorenz J. Mowry, Elyria, Ohio, assignors to Gregory Industries, Inc., Detroit, Mich., a corporation of Michigan.

A special type of a welding gun having a magnetizable metal tube within an insulation material carrier body is disclosed in this patent.

2,788,434—Welding Stud Assembly—Hugh M. Eaton, Jr., Elyria, Ohio, assignor to Gregory Industries, Inc., Detroit, Mich., a corporation of Michigan.

Eaton's patented stud assembly includes a body and at least two weldable metal members mechanically secured to and carried by the body, but with the members being electrically insulated from the body and from each other. The metal members are adapted to be welded to a common workpiece.

2,788,435—Ferrule—Joseph Maras, Lorain, Ohio, assignor to Gregory Industries, Inc., Detroit, Mich., a corporation of Michigan.

A locating ferrule for stud welding a rectangular shaped stud to the surface of a bar of the same width as the stud is disclosed by this patent.

2,788,436—Automatic Laminated-Assembly Welding—Lloyd W. Young, Elizabeth, and Frank J. Pilia, West Orange, N. J., assignors to Union Carbide and Carbon Corp., a corporation of New York.

In this patented method, a laminated assembly is progressively formed into a column and the assembly of the column is moved through a welding station. The laminations are compressed at the welding station and the edges of the laminations are welded together by torch welding means aimed at such column as moved through the welding station.

2,788,463—Arc Electrode Feeding Control—Harry E. Kennedy, Berkeley, Calif., assignor to Union Carbide and Carbon Corp., a corporation of New York.

This patent is on arc electrode feed control apparatus and an electrode feed motor and feed roll driven thereby are provided. An idler roll presses a fusible electrode into feeding engagement with the feed roll. Such idler roll is adjustably positioned with relation to the feed roll for varying the rate of feed of the electrode. The engagement of the idler roll with the electrode feed roll is controlled by a relay and circuit means connected to the weld arc and controlled by the characteristics thereof to function to maintain the electrode feed at a rate so as to maintain desired characteristics in such weld arc.

2,789,048—Welding Steel for Joining High Strength Steels, and 2,789,049 High Strength Welding Steel—William T. De Long, West Manchester Township, York County, and Gustaf A. Ostrom, Paradise Township, York County, Pa., assignors to The McKay Co., Pittsburgh, Pa., a corporation of Pennsylvania.

These patents both relate to a high strength welding steel having from about 11 to 20% chromium therein, about 9 to 19% manganese therein, and having a specialized relationship between the amount of manganese and nickel present in the steel. Other specified limits for carbon and other materials are required by the patents.

2,789,065—Aluminum Bronze Weld Rod—Francis E. Garriott, West Allis, and John F. Klement, Milwaukee, Wis., assignors to Ampco Metal, Inc., Milwaukee, Wis., a corporation of Wisconsin.

The patented weld rod comprises a core made from about 1 to 10% aluminum, up to 5% iron, up to 5% nickel and the balance being substantially all copper. A metal sheath is applied to the outer surface of the core and comprises over 90% aluminum and smaller amounts of other materials to complete the coating material.

2,789,074—Fluxes for Dip Brazing Aluminum—Mike A. Miller, New Kensington, Pa., assignor to Aluminum Company of America, Pittsburgh, Pa., a corporation of Pennsylvania.

This new flux consists essentially of about 10 to 30% active fluoride components and between 70 and 90% non-fluoride vehicle components. Between 4 and 8% aluminum fluoride and 4 to 20% barium fluoride are present in the flux.

2,789,195—Apparatus for Stress Relieving Welded Pipe Joints—Richard M. Hortvet, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

Hortvet's patented apparatus is for stress relieving welded girth joints in relatively large diameter tubular articles. The apparatus has a mobile frame adapted for positioning within the tubular article and a generally circular induction heating coil is supported by the frame in alignment with the welded joint to be stress relieved and which heating coil has a diameter slightly smaller than the internal diameter of the article. Means are provided for supplying electrical energy to the induction heating coil when the coil is expanded into engagement with the pipe joint to induce a current in the article (pipe joint) to heat the same and relieve the stresses therein.

2,789,202—Welding Apparatus—Amos L. Quinlan, La Grange Park, Ill., assignor to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

The patented welding apparatus includes a plurality of welding electrodes mounted on flexible arms, and electrode means for cooperating with the electrodes to oppositely engage a plurality of parts to be welded together. These electrodes and electrode means are relatively movably positioned to close on the parts positioned therebetween. A pair of wire spring combs are mounted on the arms positioning the welding electrodes and carry a plurality of contacts. When an electrode positioned by a particular arm is brought into proper welding engagement with an electrode means, the associated contacts on the spring combs are adapted to close the welding circuit for such electrode and electrode means. Actuating means are provided for providing welding energy to the electrode and electrode means if all pairs of contacts of the combs are closed, but which means will not function if certain of the contacts are not properly closed.

2,789,924—Low Alloy Coated Electrodes with Low Carbon Core—Nicholas C. Jessen, Akron, Ohio, assignor to The Babcock & Wilcox Co., New York, N. Y., a corporation of New Jersey.

2,789,925—Coated Weld Rods with Low Carbon Core—Nicholas C. Jessen, Akron, Ohio, assignor to The Babcock & Wilcox Co., New York, N. Y., a corporation of New Jersey.

These patents relate to special coated weld rods with low carbon cores. The weld rod has a low hydrogen type mineral coating thereon in which Molybdenum is present together with an element from the group made of Chromium, Manganese, Silicon, Nickel and Vanadium. The cores of the electrodes are made either from substantially pure iron, or ferritic steel, each of which has a carbon content not exceeding 0.05%.

Better Welding!

ONE TOUGH JOB
—three magnet frame pieces of different thicknesses, projection welded in one operation

Improved non-synchronous performance with Square D's NEW SLOPE CONTROL

Heat—
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BETTER AND MORE PROJECTION WELDS through more uniform distribution of welding current.

PERMITS WELDING NON-FERROUS METALS. Reduced "spitting" at electrodes improves appearance of aluminum and other non-ferrous welds—extends electrode life.

DESIGN FEATURES

Matched Enclosures. Slope Control enclosure matches Square D Non-Synchronous Welder Controller (Nema N2), shown at right. Also matches individual Square D welding timer or contactor enclosures.

Simplified Circuit, standard components, and heavy-duty construction.

Write for Bulletin 8990 EWG. Address Square D Company, 4041 North Richards Street, Milwaukee 12, Wisconsin.

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For more details circle No. 12 on Reader Information Card

NEWS of The Industry

Welding Featured at Refresher Course for Pipefitter Teachers

In 1954 the United Association of Journeymen and Apprentices of the plumbing and pipefitting industry conducted a contest at Purdue University. The objective was to determine the degree of skill attained as well as to discover the most skillful apprentice. At the same time, a seminar-type conference was held for teachers of pipefitting and plumbing apprentices.

This meeting was so successful that it has since become an annual affair. In 1954 approximately 60 attended. 165 were registered in 1955. In 1956 the number had grown to 208. In 1957 the figure reached 361. This was the fourth annual meeting to be held at Purdue University in Lafayette, Ind., August 11–16.

Such contests are not new. Contests of manipulative skill are held in many cities and in many countries, but the Purdue activity is unique, in that a seminar-type conference is conducted simultaneously with an apprentice contest. The welded joints are judged and the skill manifested indicates the quality of the instruction received by the students. The actual teachers of these apprentices have the opportunity of learning the latest processes and developments in the welding industry.

This activity, under the direction of Peter T. Schoemann, general president, and Joseph P. Corcoran, director of training, has grown until it is one of the outstanding examples of apprentice training. Representatives from the boilermakers, electricians and ironworkers, together with observers from other industries and other schools, attended the 1957 conference to study the program, method of teaching and to evaluate the effects.

The Apprentice Training Committee of the AWS was invited to plan the welding section of the program, and a course was ultimately prepared and approved. Competent men from industry were then obtained to instruct the teachers in the latest methods, proc-

Instructors of apprentices watching demonstration of inert-gas shielded arc welding during one of the class periods

Contest specimen being tack-welded by an apprentice plumber

Silver brazing techniques demonstrated by Barrie Hackett of United Wire Supply Co. Twice as many sessions were devoted to this process as were available in 1956

An apprentice pipefitter assembling his fabricated specimen ready for the contest judges

Robert Camp, U.A. apprentice coordinator, introduces Arthur Kugler, AWS Technical Activities Committee chairman. Mr. Kugler made the principal address to all instructors, apprentices and guests

Ralph Minga of The Linde Co. lecturing on pipe-end preparation for welding to instructors from all parts of the country

esses and materials.

Six members of the AWS Apprentice Training Committee were assigned to the Conference and each of these six members instructed eight different classes on pipe welding. Nearly four hundred teachers were instructed in these 48 classes.

Larry Ash of Lincoln Electric Co. and Bob Bercaw of Hobart Brothers Co. dealt with covered-electrode arc welding. Dan Burich of Air Reduction Sales Co. and Jim Howery of National Cylinder Gas Co. covered oxyacetylene welding. Ralph Minga of the Linde Co., together with H. A. Sosnin of Tube Turns, gave instruction on inert-gas metal-arc welding. Arthur N. Kugler of Air Reduction Sales Co. and Chairman of the Technical Activities Committee gave the principal talk. On Wednesday evening, he spoke on the general principles and applications of pipe welding, giving reasons for using certain processes and explaining why, when and where to use them. Clarence E. Jackson, Chairman of the Educational Activities Committee, also was present at the conference.

In 1956, there were approximately twelve sessions on silver brazing and soldering. This year there were twenty-four sessions. These classes were conducted by Barrie Hackett of United Wire Supply Co. and William Mulholland of Chase Brass and Copper Co.

The contest for apprentices involved the cutting of steel pipe with the oxy-acetylene torch, the making of butt welds on steel pipe and silver-brazed joints on copper and brass pipe. The contest showed that a high standard of skill had been attained.

The winners of first places in the contest were Lawrence Hollyer, Detroit, for the pipefitters and Robert Neubert, St. Louis, for the plumbers.

The impact and value of this educational program is being felt very strongly throughout the entire piping industry. It is vigorously supported by the Mechanical Contractors Association and the National Association of Master Plumbers.

Welding Engineering Fellowship at Ohio State

Establishment of a new Air Reduction Fellowship in welding engineering at Ohio State University was announced today by Gordon B. Carson, dean of the College of Engineering.

Designed to encourage graduate research and study in the field of welding engineering, the fellowship will carry a stipend of $2400 a year for unmarried and $3000 yearly for married recipients.

It has been made possible by a grant from the Air Reduction Co., Inc., New York, N. Y., through the University Development Fund.

Persons interested in applying for the new fellowship should write immediately to Prof. Roy B. McCauley, chairman, department of welding engineering, Industrial Engineering Building, Ohio State University, Columbus 10, Ohio.

At the same time the applicant should send a transcript of his college credits to the Advanced Admissions Office, Administration Building, of the university.

New M&T Distributor

Odland Iron Works, 829 Spencer St., Toledo, Ohio, has been appointed a distributor for Metal & Thermit Corp.'s line of Murex arc welding electrodes, machines and accessories.

Sales Gain in Resistance Welding

Shipments of resistance welding equipment by members of the Resistance Welder Manufacturers' Association during July surpassed June shipments by nearly 17%, according to statistics compiled by the Association.

July shipments were more than $3 million, making this the third month of the year in which that figure has been reached, and the fifth consecutive month above $2½ million.

A slight increase in new orders over the previous month was reported and a backlog of more than $9½ million was indicated at the end of the month.

Hobart Appoints Distributor

The Industrial Air Products Co. of Portland, Ore. has been appointed northwest distributor for the Hobart line of welding machines and electrodes, according to President Gilbert Schnitzer.

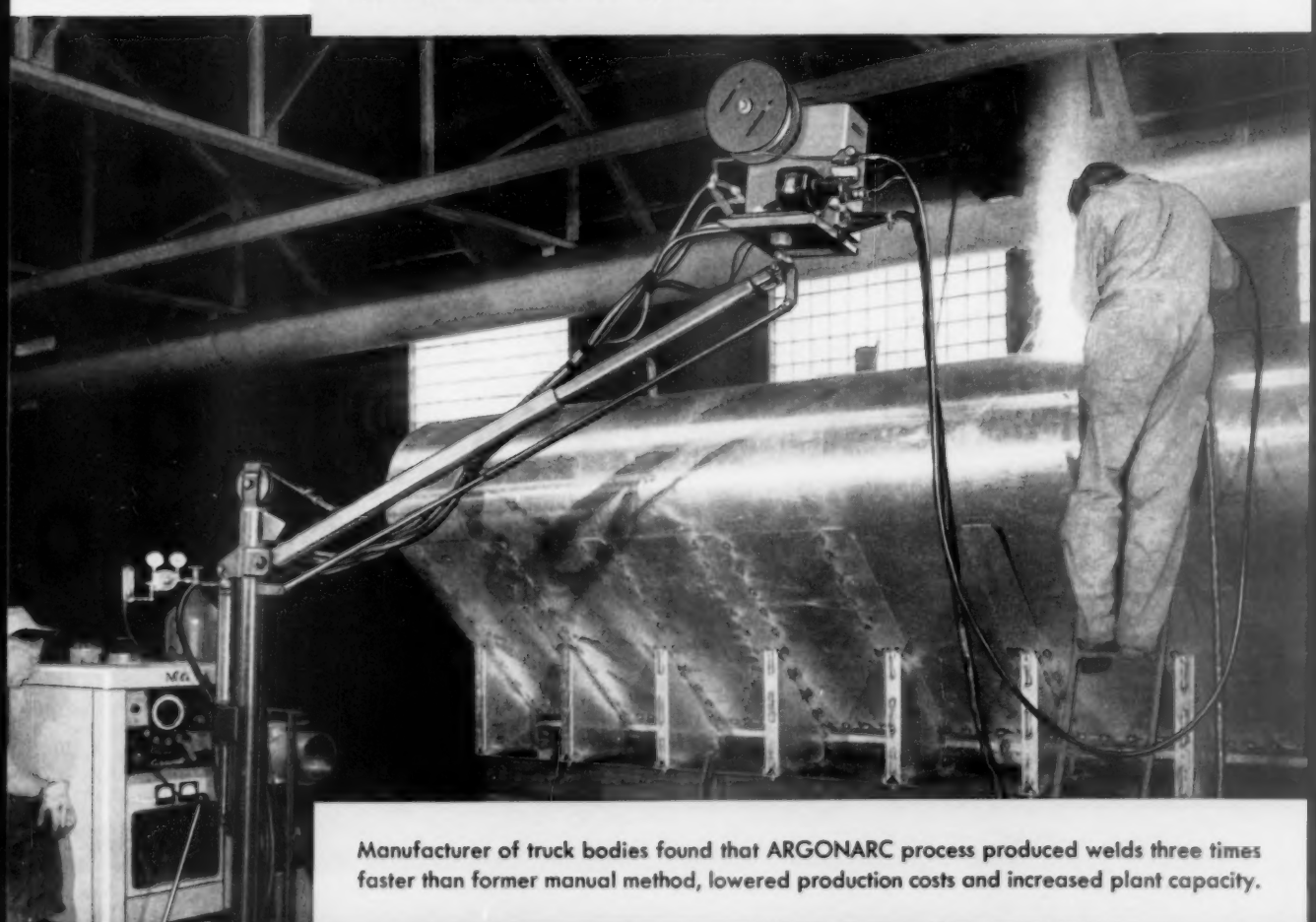
Industrial Air, headquartered in Portland, maintains branch offices in Seattle, Spokane, Yakima, Kennewick, Pendleton and Medford as well as in New Orleans and Guam.

Harnischfeger Appoints Florida Dealer

M. O. Monsler, general sales manager for the Welding Division of Harnischfeger Corporation, Milwaukee, Wis., has announced the appointment of Florida Gas & Chemical Corp., Hollywood, Fla., as dealer for the complete line of P&H welding equipment throughout southern Florida.

The P&H line of welding equipment includes a complete complement of

Fabricator of gasoline storage tanks reports that DUAL SHIELD process has reduced welding costs by 25 per cent.



Manufacturer of truck bodies found that ARGONARC process produced welds three times faster than former manual method, lowered production costs and increased plant capacity.

Now! Better Welds at lower costs than ever before possible

If the cost of welding is a major factor in your operations, here is news that can have an important bearing on your future profits.

Two new NCG welding processes—DUAL SHIELD* for mild steel and ARGONARC* for stainless steel and all other weldable metals—have proved in actual use that they can reduce welding costs to record-breaking low levels.

Both processes use the same NCG equipment—basically a control and wire drive unit used either with the NCG Automanual* welding gun or the NCG automatic torch. DUAL SHIELD welding is done with a coiled flux-cored electrode, with CO_2 as a shielding gas. ARGONARC welding uses coiled welding wire and argon as the shielding gas.

Using the Automanual welding gun with DUAL SHIELD electrode, a weldor can deposit from four to five times as much weld metal as with conventional manual electrodes. Penetration is deeper, welds are of high quality and slag is practically self-removing. The ARGONARC process offers comparable advantages. In both processes, welding efficiency is further increased by using the automatic torch.

Ask the NCG office in your area to show you what these new processes are doing for others. Or write for informative literature.

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FOR
MILD STEEL, LOW HYDROGEN AND HARD-FACING
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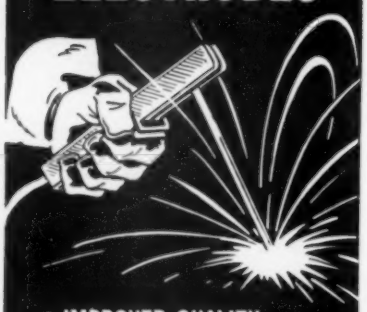

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National-U.S. Radiator Corporation

Circle No. 14 on Reader Information Card

a-c, d-c, a-c/d-c welding machines, a wide variety of electrodes and manual and semiautomatic welding positioners with capacities up to 100,000 lb.

In addition, the Milwaukee firm manufactures overhead electric cranes and hoists, power cranes and shovels, diesel engines and prefabricated homes.

Promotions at National Welding Equipment

Ernest L. Mathy, president and general manager, National Welding Equipment Co., of San Francisco, Calif., announces the promotion of the following individuals: Henry L. Pohndorf, formerly vice-president in charge of sales, has been advanced to the position of vice-president and works manager; Bart Peacock has been promoted to the position of sales coordinator; John H. Calderoni, former general plant superintendent, has been promoted to the position of development engineer; and Paul Yeoman, former assistant general plant superintendent, has been advanced to the position of general plant superintendent.

Ampco Builds in Texas

Ampco Metal, Inc. will build a $200,000 branch foundry at Garland, Tex., near Dallas to meet its growing market in the industrializing Southwest.

The 15,000 sq-ft plant, expected to be in operation by March 1958, will include sand and centrifugal foundries, heat treating facilities and some machining operations. It also will become the location of Ampco's principal sales and services offices in the Southwest.

The Milwaukee firm already has developed substantial markets in the chemical, petroleum, aircraft and metalworking industries in the Southwest, many of which are strongly centered in the Dallas area.

J. D. Zaiser, company president, said manufacturing facilities will enable production of bronze castings weighing up to 1000-lb each and the supplying of aircraft quality alloys to engineering specifications for a wide variety of services.

NCG Distributes Oxygen from Louisville Plant

National Cylinder Gas Co. has announced that it has begun distribution of high-purity oxygen for industrial and inhalation therapy use this week from a new plant in Louisville, Ky.

Charles J. Haines, president, said in Chicago that construction of the unit reflects the increasing demand for oxygen resulting from Louisville's steady industrial growth. The new NCG facility has storage for large quantities of liquid oxygen.

Mobile tube trailers as well as portable cylinders for distribution to area customers will be filled by the new NCG oxygen plant.

Cesco Moves to New Quarters

After doing business for over half a century on Chicago's near west side, the Chicago Eye Shield Co. has announced plans to move to new and bigger quarters which will give the company an urgently needed boost in productive capacity. "Our new plant will give us at least 50% more productive area," reports Mr. Robert Malcom, Jr., President, "a factor of great importance in that our orders have far exceeded our volume in recent years. We feel fortunate in being able to secure such a well layed out, modern building that is readily adaptable to increased production through simplified material handling."

Founded in 1903, the Chicago Eye Shield Co. has been a pioneer in the development of all types of industrial protective equipment. At present the Cesco line offers a complete line of head and eye protective equipment.

New address of the Chicago Eye Shield Co. is 2727 W. Roscoe, Chicago 18, Ill.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1958 Spring Meeting and Welding Show:

April 14–18, Statler Hotel, St. Louis, Mo.

ASM

November 4–8, 1957. Thirty-ninth National Metal Exposition & Congress, concurrently with Second World Metallurgical Congress, International Amphitheatre, Chicago, Ill.

NWSA

Southeastern Zone Meeting:

December 2–3, 1957, Atlanta Biltmore, Atlanta, Ga.

Southwestern Zone Meeting:

December 5–6, 1957, The St. Anthony, San Antonio, Texas.

For more details, circle No. 15 on Reader Information Card ⟶

Plant, Research Laboratories and World Headquarters

BETTER ORIGINAL FASTER
Low Temperature EUTECTIC WELDING ALLOYS
STRONGER WELDS

EUTECTIC Welding News

PUBLISHED BY EUTECTIC WELDING ALLOYS CORPORATION, 40-40 172 STREET, FLUSHING 58, NEW YORK, N. Y.

OVERLAY TECHNIQUE SAVES $2000

Photo shows hammer heads in various stages. Far left shows new hammer. Others show cracking and peeling to different degrees. These were overlayed with ordinary materials.

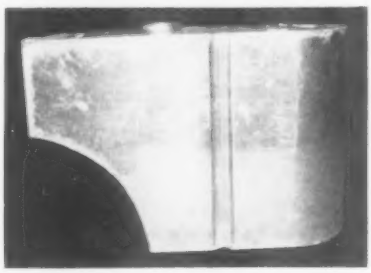
Overlaying worn crusher hammers with conventional welding materials proved costly to a Minnesota brick plant. Overlays failed in less than a week, repair costs mounted.

The Eutectic District Engineer advised that high heat needed to apply the conventional materials actually weakened the overlay. The answer was to use as low amperage as possible.

Tests were run on hammers rebuilt in this way: First, hammer faces were padded with EutecTrode 680 AC-DC. This very high strength alloy, applied at very low amperage, acts as a cushion for the overlay. Next, EutecTrode 10 for super high hardness (RC 64-68) was applied over the padding layer, giving maximum abrasion resistance. For added protection against severe pounding. EutecTrode 12 was applied to corners.

At the start of the test, all hammers weighed 21½ pounds. After two weeks hammers with conventional overlays were down to 16¾ pounds. Six weeks later hammers with Eutectic repaired overlays were still 18¾ pounds. Repairs, reports the company, which once cost $690 every six weeks, were now reduced to $369 . . . savings close to $2,000 a year . . . almost 50%. Now, hammers need attention only every six weeks rather than every week . . . and downtime has been cut by 84%. ***(B-13)***

EXTRUDED COATING SOLVES ALUMINUM WELD PROBLEM



Welds on aluminum tanks were cracking right down the middle. Difficulty was caused by the uneven flow of flux, common when flux is put on rod by old fashioned dipping. Eutectic's Low Amp EutecTrode 2101, with *extruded* "frigid arc" flux coating was used. Because of smooth, even, *extruded* application of flux to rod, it is spatter-proof and easy to control. EutecTrode 2101 is strong, too—with an ultimate tensile strength of 34,000 psi to make joints up to three times stronger than those obtained with conventional welding materials. Tank fabricator reports cracking problems solved . . . production increased by 40%. ***(B-14)***

CONCRETE FORM'S INTERIOR BRACING WELDED WITH SUPER-STEELTECTIC 110

An Illinois welding shop received an order for six concrete septic tank forms. Welds on this job were in all positions, and interior bracing consisted of heavy angles set against sheet steel. Using conventional mild steel electrodes, weldors soon ran into difficulty. Many angles and braces made the arc hard to maintain, and the deposit could not be properly controlled for the strong welds needed.

Super-SteelTectic 110, a new universal, all position EutecTrode was suggested by the Eutectic District Engineer. The highly exact control of penetration possible with this alloyed steel electrode gives excellent results on joints of varying thicknesses. The lower amperage minimizes danger of burn through, and eliminates spatter. Welds are exceptionally strong, too, as Super-SteelTectic 110 deposits weld metal near 110,000 psi tensile. ***(B-15)***

Q. We have a bulldozer drive shaft, 3⅝ inches in diameter, that sheared in half. What repair procedure is recommended?

A. Vee the shaft out on either side of the break and clean thoroughly. A square butt joint is not recommended. High strength patented EutecRod 16FC, 3/16-in diameter should be used together with Eutector 16B Flux, which is painted on prior to heating. Joint should be designed with a gap to insure deposited metal throughout.

Q. Our flux for stainless steel brazing breaks down at about 1700°F. What can you recommend?

A. The "Eutector" series of T (Triple Strength) fluxes is designed for applications requiring sustained heating cycles or higher temperatures than are normally used in silver brazing. Consequently, the T fluxes are suitable for temperatures up to approximately 2000°F.

Q. In production of surgical instruments we have been using a conventional silver alloy that tarnishes badly. Require a thin flowing silver alloy of the same melting temperature that will retain luster.

A. EutecRod 1800 is free of cadmium, the element most responsible for tarnishing. Bonding temperature is approximately 1100°F. EutecRod 1800 is of the eutectic-type, having a narrow plastic range, and noted for its thin flowing properties.

Eutectic Welding Alloys Corporation
40-40 172nd Street, Flushing 58, N.Y.

Gentlemen:

I would like further free information on the following:

☐ B-13 ☐ B-14 ☐ B-15

☐ Free: New 1958 180 page pocket Welding Data Book.

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"EUTECTIC" WELDING HEADLINES • TIME-MONEY-MACHINERY SAVERS

Air Products Adds to Engineering Staff

Three chemical engineers recently joined the research department of Air Products.

Dr. Leo DiRicco, Ph.D. in chemical engineering, University of Colorado, will perform economic and technical evaluation of research projects.

Willard L. Ent, who comes to Air Products as a senior chemist, has previously worked in the analytical research and instrumentation fields.

Albert M. Momenthy, a recent graduate of the University of Massachusetts, will serve as a research engineer.

WANTED: A graduate engineer with some experience to become Technical Secretary of a non-profit scientific research organization in the Metals field who can in a few years assume complete managerial charge of the work. Metallurgical and Welding Research experience desirable. Please give full particulars, age, accomplishments and starting salary desired. Box V-346, The Welding Journal.

WELDING ENGINEERS FROM FIVE CONTINENTS

Welding engineers from nearly every continent of the world watch a demonstration of semiautomatic submerged-arc welding at the plant of the Lincoln Electric Co. in Cleveland, Ohio. These engineers, from Europe, Asia, South America, Central America, North America and Africa, recently spent four weeks with Lincoln engineers studying new welding techniques and equipment and discussing world-wide welding problems. All the men are engineers for the Armco International Corp.

NEW AIRCO "DUAL RANGE" FLOWMETERS

VERSATILE. Designed to meter an individual gas or proportion any number of gases. Attaches to cylinder regulators, pipeline regulators, pipeline direct or bench or wall mounted.

WIDE OPERATING RANGE. One meter covers flows formerly requiring more than one device. Easy to switch from high to low range reading.

ACCURATE. Accuracy of the dual range flowmeters is not affected by back-pressure, provided air-inlet pressure of 30 psi is maintained. When 30 psi inlet pressure is maintained, accuracy is within 3% of lower range, slightly less in upper range.

EASY READING. All Airco flowmeters are provided with black graduated scales fixed on the tube against an orange background. Accurately read at a glance.

The new Airco Dual Flowmeters are ideal for inert-gas welding, flushing molten metals, laboratory service and many other industrial uses. Simple, solid construction means minimum maintenance and long service life. Ask your Authorized Airco Dealer for complete information or contact Airco direct.

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INTERNATIONAL WELDING NEWS

IIW Invites American Authors to Submit Papers

The International Institute of Welding invites all American authors to submit unpublished papers for consideration and possible presentation at the Annual Assembly to be held in Vienna from June 29 to July 6, 1958. The Public Session will take place on June 30th and will be devoted to the theme "Welding in the Chemical Industry." The following phases of this general theme will be treated:

(1) Influence of the method of welding, of preheating and of finishing operations on the properties of welded assemblies in comparison with those of the parent metal.

(2) Welding of clad metals; lining.

(3) Special problems in the welding of equipment for the chemical industry and for nuclear plants.

(4) Design and calculation of welded products working under high pressure and at high temperatures.

(5) Typical examples of welded constructions.

All papers must be non-commercial and written in English, French or German. On the first page there shall be stated: (1) Title of the paper in the three aforementioned languages; (2) Surname, christian name, title, position and address of the author; and (3) Summary of the paper in the three languages—not to exceed 100 words. The papers shall be typewritten on one side in double spacing on paper size 210 x 297 mm (type A4, UNE Standard 1011); the text shall not exceed 14 pages exclusive of photographs and drawings.

Authors are asked to limit the number of photographs and drawings to 10 per paper. The photographs shall be sized 90 x 120 mm and printed on high-gloss paper. The drawings shall be made in Indian ink on hard white paper so that they are ready for block-making. When the papers are printed, the width of the columns will be 75 mm; illustrations will therefore have to be reduced in size, and so it is essential that the originals should be very clear and that any writing on them should be sufficiently large to be legible after reduction.

All papers submitted will be examined by a selection committee composed of Austrian welding experts. This committee will decide on the papers to be prepared at the Public Session and on their publication. The papers will be divided into groups in accordance with their subject for presentation at the Public Session; each group will be presented by a rapporteur.

All authors will be informed after Jan. 31, 1958, whether or not their papers will be published.

Dec. 1, 1957, is the deadline for the title of the paper, surname, christian name, title, position and address of author.

The complete paper must be submitted not later than Jan. 15, 1958.

All correspondence concerning these matters should be directed to: Österreichisches Organisationskomitee, IIW/IIS Jahresversammlung 1958, c/o Schweisstechnische Zentralansalt, Wien XVIII, Schumanngasse 31, Austria

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Aronson Twinner Permanent Magnetic Clamps. six models with thousands of uses in welding set-up work. Write for bulletin.
Aronson Universal Balance Positioners (T. M. Reg.) position your weldments effectively, instantly for downhand welding. Capacities to 2000 lbs.
Rugged Head and Tail Stock for positioning bulky weldments between centers. Table Backup for Zero Deflection. Magnetic Braking. Capacities to 160,000 lbs.
Write for detailed engineering data
Quality POSITIONERS by Aronson MACHINE COMPANY
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For more details, circle No. 18 on Reader Information Card→

CUT WELDING COSTS WITH

Up-to-the-minute designs

G-E Convertible Ignitron has built-in thermal-contact bracket (circle) that will carry a thermostat for over-temperature protection, or for water regulation. Thermostat which is shown here is equipped with flying leads.

Convertible Ignitron above has a terminal-block thermostat. Bracket mounting of thermostat permits the same ignitron to be used in standard or temperature - controlled applications. You save stocking two tubes.

More hours of dependable service per dollar!

Here's why!

STABILIZED STAINLESS-STEEL JACKETS

General Electric uses *stabilized* steel for both inner and outer ignitron water-jackets. Characteristics of this material—its expansion and contraction, strength, chemical content—do not change with time or use. G-E ignitrons retain their full structural strength for life, adding to dependability and cutting tube replacements.

HIGHEST-QUALITY IGNITORS

General Electric ignitors—specially made and tested—will outlast others by as high as 2 to 1. Examples of 4-years-and-over G-E ignitor life are common; also cases in which G-E ignitors have outlived the tube. Carefully controlled materials; holding the ignitor resistance to close limits; precision grinding—these are reasons-why.

CONTROLLED-GRAPHITE ANODES

By using a specially-developed electronic grade of graphite, with both density and size of particles controlled to tight limits, General Electric is able to build ignitron anodes that stand up under extremely long and hard usage. The anode graphite is further treated at the General Electric factory for maximum life in heavy-duty service and under high-temperature conditions.

TRIPLE-DISTILLED-MERCURY POOLS

Mercury in G-E ignitron cathode pools is distilled to a point where impurity content is only 1 in 100,000 or less. Organic impurities, which can bring about gas formation, and inorganic materials, which can cause the ignitor to plate over, both are held to a virtually irreducible minimum. Increases tube dependability.

FACTORY-TESTED AT FULL RATINGS

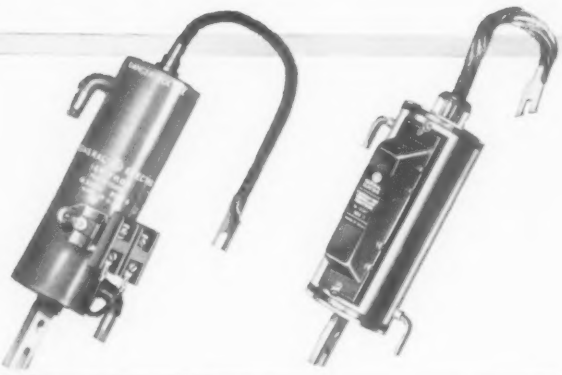
Exclusive with General Electric is the special factory test equipment that operates G-E ignitrons at full ratings under actual welding conditions. You buy tubes proved-in-advance for service in your plant. Every General Electric ignitron, moreover, is checked at the factory for the possibility of vacuum or water-jacket leakage.

CONVENIENT SLIP-ON TERMINALS

No more need to remove the terminal bolts completely when installing or replacing General Electric welding ignitrons! Merely loosen the nut and slip off one terminal with its slotted design, slip on the new terminal—then re-tighten. It's as easy and fast as that, and you run no risk of misplacing the nut-and-bolt assembly. This up-to-date feature saves you time and trouble.

G-E LONG-LIFE IGNITRONS!

meet every replacement need.



General Electric Plastic-coated Convertible Ignitron has a plastic covering to shield workers from hazardous voltages. Plastic is red for warning. "Danger . . . voltage" is stamped on outside of each tube conspicuously.

G-E Temperature-controlled Ignitron is the finest tube of its kind. Over-temperature control . . . water regulation . . . both are built in. The tube is pre-adjusted at the factory for lifelong efficiency of operation when installed.

Shows you how to squeeze maximum value out of every ignitron dollar! This complete guide to ignitron care and maintenance is a "must" for your shop files. Solves dozens of ignitron operating problems; answers scores of questions. Get your *free* copy from your local G-E tube distributor!

You cut welding costs with G-E ignitrons because (1) their life-span is greater, giving you more service hours per dollar, and (2) G-E ignitrons are more dependable, requiring minimum tube replacement. Welder downtime is reduced.

Quality of General Electric ignitrons sets the pace for the industry. Study the advantages of these tubes at left. Every design plus can be entered on the credit side of your plant ledger—means a saving in upkeep, in inventory of replacement tubes to be carried on hand, in non-productive welding time.

Check, too, the wide range of G-E ignitrons manufactured and available to you! Convertible types . . . . . G-E temperature-controlled ignitrons . . . . . plastic-coated tubes for extra safety. All can be obtained in 40-, 140-, and 355-amp capacities. Every welder need is met. You can have G-E top ignitron quality right through your plant, with the greater economy—immediate and long-term—this brings.

And your tube source is conveniently close at hand. Your General Electric tube distributor—right in your area—stocks G-E ignitrons, knows ignitrons, knows your plant requirements, makes fast deliveries to your door. Phone him today! *Distributor Sales, Electronic Components Division, General Electric Company, Owensboro, Ky.*

Progress Is Our Most Important Product

GENERAL ELECTRIC

161-105

PERSONNEL

Lipps and Bichsel Promoted by Westinghouse

The appointments of Richard C. Lipps as manager, and Harry J. Bichsel as engineering manager of the welding department have been announced by Westinghouse Electric Corp.

In succeeding W. J. Delaney, Jr., now manager of the Westinghouse X-Ray and industrial electronics division, Mr. Lipps has managerial responsibility for the company's arc welding activities. At plants located at Buffalo, N. Y., and Montevallo, Ala., the welding department is engaged in the development, manufacture and marketing of a broad range of welding products, including a-c and d-c welding machines, accessory equipment, and automatic and semiautomatic welding apparatus and electrodes.

Mr. Lipps was formerly assigned to the headquarters marketing and consumer products group at Pittsburgh. He is an electrical engineer and a member of the AMERICAN WELDING SOCIETY.

Mr. Bichsel joined Westinghouse in 1940 as a control engineer working on industrial electronics and resistance welding controls. Before his assignment as engineering manager, he had been manager of Westinghouse specialty products engineering. Mr. Bichsel is also a member of the AMERICAN WELDING SOCIETY.

Siegel and Williams at Naval Experiment Station

J. Henri Siegel and W. Lee Williams have been appointed to superintend the Technological Processes Division and the Metals Division, respectively, of a newly established Metallurgy Department at the U. S. Naval Engineering Experiment Station, Annapolis, Md.

The Metallurgy Department is the first of four major specialized departments being established in the reorganization of the Station's technical laboratories. The new department unites the work of the former Welding and Metallurgical Laboratories, and is headed by Mr. William C. Stewart, metallurgical scientist, of Round Bay, Md.

Mr. Siegel has been employed at the Experiment Station for 23 years. He is a native Baltimorean, attended Baltimore Polytechnic Institute and is a graduate of Johns Hopkins University

J. H. Siegel

from which he received his Bachelor's Degree in 1931. In 1956, he became Superintendent of the Station's now disestablished Welding Laboratory, and held that position until his present appointment as Superintendent of the Metallurgy Department's Technological Processes Division.

Mr. Siegel is a member of the AMERICAN WELDING SOCIETY. He represents the Experiment Station on the American Society for Testing Materials Committee E-7 for Nondestructive Testing, and is a member of the American Institute of Electrical Engineers Committee for Fundamental Research of the Welding Arc. He also holds a patent for his recent invention of an "Apparatus for Testing Tube Welds Under Pressure at High Temperature."

Mr. Williams is a native of Clarksburg, W. Va. He received his Bachelor's Degree in Chemical Engineering from Antioch College, Yellow Springs, Ohio, in 1941. His college training included four years of cooperative work in metallurgy at Battelle Memorial Institute.

Sauter Named by Westinghouse

B. W. Sauter has been named general manager of the Westinghouse electronic tube division located in Elmira, N. Y. The appointment was announced by Chris J. Witting, vice-president in charge of Westinghouse Electric Corp.'s consumer products divisions. Mr. Sauter replaces R. T. Orth, vice-president, who resigned from the company August 1st to take an executive position with Sanders Associates, Inc., of Nashua, N. H.

Mr. Sauter, who has been manager of the receiving tube operations of the division, will now have over-all responsibility for the tube division, including the cathode-ray tube and power plant in Elmira, as well as the receiving tube plant in Bath, N. Y.

Hinkel Joins Welding Illustrated

The appointment of Hubert G. Hinkel as associate editor of Welding Illustrated and Industry and Welding, two of the publications of the Industrial Publishing Corp. of Cleveland, was announced today by Thomas L. Demp-

H. G. Hinkel

sey, general manager of Industry & Welding.

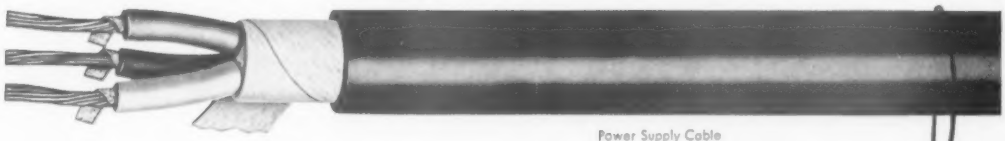
Mr. Hinkel began his career in the welding field as a sales engineer for the Lincoln Electric Co., and later served in the same capacity with Williams and Co. Prior to joining the magazines, Mr. Hinkel was with the General Electric Co.'s Welding Division as manager of Cleveland welding sales. He is a member of the AMERICAN WELDING SOCIETY.

Metcalf Promoted by Airco

W. P. Metcalf, purchasing agent for the National Carbide Company division of Air Reduction Co., Inc., has been appointed to the post of assistant purchasing agent of the parent company, it was announced by R. N. Chapin, general purchasing agent. Mr. Metcalf, with the company since 1942, has handled purchasing activities for the National Carbide division since 1944. In his new capacity he will assist Mr. Chapin in all purchasing functions of the corporation.

Power Supply Cord

If it's worth engineers' time...



Power Supply Cable

...it's worth engineered cable

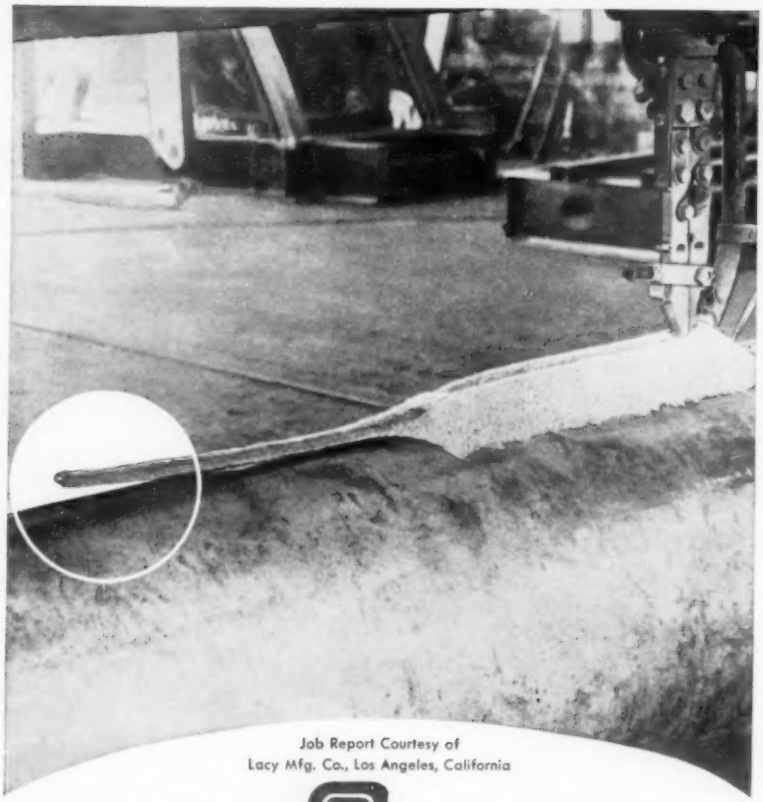
Belden
WIREMAKER FOR INDUSTRY
SINCE 1902
CHICAGO

5-W

Magnet Wire • Lead and Fixture Wire • Power Supply Cords, Cord Sets and Portable Cord • Aircraft Wires
Welding Cable • Electrical Household Cords • Electronic Wires • Automotive Wire and Cable

For more details, circle No. 19 on Reader Information Card

Now, submerged arc stainless welds with slag that "pops-off"



Job Report Courtesy of
Lacy Mfg. Co., Los Angeles, California

WELD WITH ARCOS

Stainless Wire and Arcosite Flux

Arcos research and experience with stainless weld metal now pays you *another dividend*—for the first time . . . consistently *self removing slag!* On the job above, submerged arc welding of a section of pipe for petroleum equipment, two passes were made with 1/8" coiled CHROMENAR KMo Stainless Wire and ARCOSITE S-4 Flux. As the photo shows, the cooling slag is lifting free by itself . . . leaving a clean, smooth bead. Think what this can mean to you on your own submerged arc welding jobs . . . saving time and money . . . better welds than ever before. ARCOS CORPORATION, 1500 S. 50th St., Philadelphia 43, Pa.

Circle No. 20 on Reader Information Card

Little Appointed by U. S. Steel

Robert C. Little has been appointed as a technologist in the Bar, Plate and Forged Products Division of U. S. Steel's Applied Research Laboratory, Monroeville, Pa. He will do research work in welding.

Mr. Little graduated in 1943 with a Metallurgical Engineering degree from the University of Pittsburgh. He comes to the Research Center from the United Engineering and Foundry Co.

Hardison and Geiser Transferred by Tube Turns

S. Merle Hardison has been appointed district manager in Philadelphia for Tube Turns, Louisville, Ky., manufacturers of welding fittings and flanges for industrial piping systems.

The announcement was made by John G. Seiler, president of Tube Turns, a division of National Cylinder Gas Co.

Mr. Hardison succeeds W. E. Geiser, who has returned to the headquarters staff in Louisville and has been assigned to an important phase of the company's expansion program.

Parks and Lederer Named by M&T

Metal & Thermit Corp., New York, announces the appointment of J. K. Parks to the post of director of purchases and traffic and G. B. Lederer to that of general purchasing agent.

Mr. Parks, formerly with Burns & Roe, Inc., joined Metal & Thermit in 1954. He became general purchasing agent in 1955 when the company's present centralized purchasing department was established under his direction.

Mr. Lederer has been with Metal & Thermit since 1941. Prior to becoming assistant general purchasing agent in 1955, he was purchasing agent at the company's plant in Carteret, N. J.

Keller Made Chief Engineer

R. J. Keller has been named chief engineer of the A. O. Smith Corp.'s Welding Products Division, which manufactures electrodes, welding equipment and direct current power sources. Formerly he was assistant to J. J. Chyle, Smith's welding research director and 1956–57 president of the AMERICAN WELDING SOCIETY.

Keller will be in charge of engineering for the company's three welding products plants at Milwaukee, Elkhorn, Wis., and Leola, Pa. He has been with A. O. Smith since 1939. Mr. Keller is a member of the AMERICAN WELDING SOCIETY.

Joyce and Thomas Join A. O. Smith

Fred J. Joyce and John P. Thomas are new sales representatives for A. O. Smith Corporation's Welding Products Division. Joyce, formerly with Metal & Thermit Co., will operate in the Oakland, Calif., area. Thomas will headquarter in Atlanta. Previously he was with Eutectic Welding Alloys, Inc.

Mr. Joyce is a member of the AMERICAN WELDING SOCIETY.

Eckert, Sterling and Sullivan Added to Lincoln Sales Force

Robert C. Eckert, Kirk H. Sterling and Francis X. Sullivan have recently joined the Lincoln Electric Co.'s district offices at Baltimore, Md.; Charlotte, N. C.; and North Haven, Conn., respectively. All three of these men were in the company's training program at the home plant in Cleveland, Ohio.

Mr. Eckert, a native Clevelander, joined the company in 1956 after receiving a degree from Cornell University in Mechanical Engineering.

Mr. Sterling, originally from Mentor, Ohio, received a degree in Economics from Purdue University. He joined Lincoln in 1956, after having served three years as an Army Engineering Corps officer.

Mr. Sullivan, a native Bostonian, received the degree, Bachelor of Science, Industrial Engineering, from Northeastern University. He joined the company after serving as an Air Force officer.

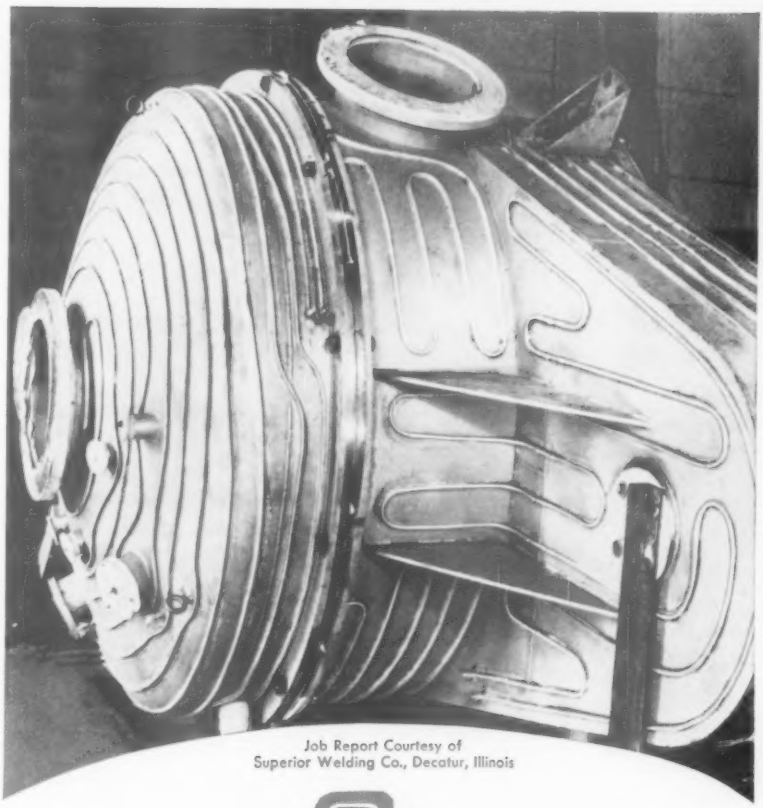
The Messrs. Sterling and Sullivan are members of the AMERICAN WELDING SOCIETY.

Kennedy Fills New GE Post

The appointment of Richard D. Kennedy to the newly-established post of advertising and sales promotion manager of the General Electric Receiving Tube Department has been announced by R. V. Bontecou, manager of marketing for the department. The receiving tube department formerly was served by the advertising section of the company's centralized tube sales operation which has been disbanded.

In his new position, Mr. Kennedy will direct advertising, sales promotion and publicity activities not only for original equipment sales of receiving tubes, but also for distributor sales of all types of GE electronic tubes, vitreous enamelled resistors, transistors and other semiconductor products, high fidelity equipment, phono accessories and the products of the company's specialty electronic components department.

When stainless welds must be VACUUM TIGHT



Job Report Courtesy of
Superior Welding Co., Decatur, Illinois

WELD WITH ARCOS

STAINLESS ELECTRODES

Shown here is a stainless steel furnace body of type 304 ELC for use under very high vacuum conditions in the casting of metals where exceptional purity is required. Arcos Chromend K-LC Stainless Electrodes were used because Arcos electrodes not only assured the proper weld metal chemistry, but also the necessary soundness to insure vacuum tight welds. Save money and future problems with long-lasting Arcos-produced welds. ARCOS CORPORATION, 1500 S. 50th Street, Philadelphia 43, Pa.

Circle No. 21 on Reader Information Card

To solve these welding problems...

Specify cam-lok

for SAFETY • SPEED • ECONOMY

Reducing overheating and current losses with positive lock CABLE CONNECTORS that release easily

EXCLUSIVE CAM-ACTION
Fibre Insulated
CABLE CONNECTORS

- Minimum resistance, high pressure contact.
- Lock tight—stay tight—release easily.
- Self-compensating for wear.

Producing indestructible shockproof waterproof CABLE CONNECTORS in minutes

cam-lok *Neoprene Insulated*
CABLE CONNECTORS

- Eliminate cable breakage at connector. Cable jacket cannot pull away. Connection smoothly tapered—won't be caught on obstructions.
- Minimum resistance when locked, yet quick disconnect. Connects all cables, #2—4/0.
- Sleeves are permanently vulcanized to cable jacket with Vulcanizing Kit.

Quickly producing vulcanized economical CABLE SPLICES AND CONNECTORS without power loss

cam-lok *Portable*
VULCANIZING KIT

- Produces a neoprene insulated cable Splice or Connector in 5 minutes, in 5 easy steps.
- Waterproof and shockproof connection . . . conductivity and insulation equal to new cable. Kit operates on 110 V. AC.

Making economical, vulcanized CABLE SPLICES in minutes

cam-lok *Neoprene Insulated*
CABLE SPLICES

- Each Splice is uniformly smooth . . . permanent . . . waterproof . . . safe . . . delivers full power.
- Economical . . . you can splice as little as two, 2′ sections together economically, which might otherwise be wasted.

cam-lok
DIVISION
EMPIRE PRODUCTS, INC.
P.O. BOX J-98, CINCINNATI 36, OHIO

Visit Our Booth No. 1337
CHICAGO METAL SHOW
Nov. 4th–8th.

Circle No. 22 on Reader Information Card

Schwitter Named by Inco

C. M. Schwitter, formerly Supervisor of Far Eastern and Latin American Technical Developments, has been promoted to head the market research activities of The International Nickel Co., Inc., according to an announcement by Lars R. Larson, vice-president and general sales manager. Mr. Schwitter will be assisted by George Hoobler,

C. M. Schwitter

formerly a member of the Steel Section of the company's Nickel Sales Department.

Mr. Schwitter joined International Nickel in July, 1930, as a research metallurgist, serving until 1936 in the company's Research Laboratory at Bayonne, N. J., where he conducted research on low alloy steels. In 1936, he was transferred to the Development and Research Division staff at the New York office to undertake development work on steels and cast irons, carrying out this activity until 1951, with the exception of the period from 1941 to 1945 when he served in the U. S. Armed Forces at the Watertown, N. Y., Arsenal as a member of the Ordnance Corps, in which he achieved the rank of lieutenant-colonel. In 1951, Mr. Schwitter was placed in charge of Far Eastern Technical Developments for the company and in 1956 his duties were expanded to embrace Latin American Technical Developments.

Author of a number of technical publications on nickel and related subjects, Mr. Schwitter is a member of the American Welding Society, American Institute of Mining and Metallurgical Engineers, American Society for Metals, British Iron and Steel Institute, American Ordnance Association, American Chamber of Commerce in Japan, Far-East America Council of Commerce and Industry and the Committee on Ferro-Alloys and Ferro-Alloying Elements of the Advisory Council on Federal Reports. He is a former chairman of the Subcommittee on Gun Forgings of the Ferrous Metallurgical Advisory

Board and a former vice-chairman of the Materials Division of the Pressure Vessel Research Committee.

Mr. Schwitter holds the degree of Metallurgical Engineer from Lehigh University. He studied also at Columbia University and New York University and is a Tau Beta Pi.

Rash Named by Alloy Rods

E. R. Walsh, III, vice-president in charge of sales of Alloy Rods Co., announces the appointment of William C. Rash to the position of field representative in the Houston area. Mr. Rash has had many years in the welding industry. His interest in welding dates

W. C. Rash

back to 1926 at which time he enrolled in the General Electric School of Welding, Schenectady, N. Y. He remained with GE for 12 years, continuing in various capacities connected with welding in the GE fabricating shops. During the war years he held the position of welding superintendent for Baldwin-Lima-Hamilton Corp. In 1947 he returned to General Electric, accepting a sales post in that company's Houston sales office.

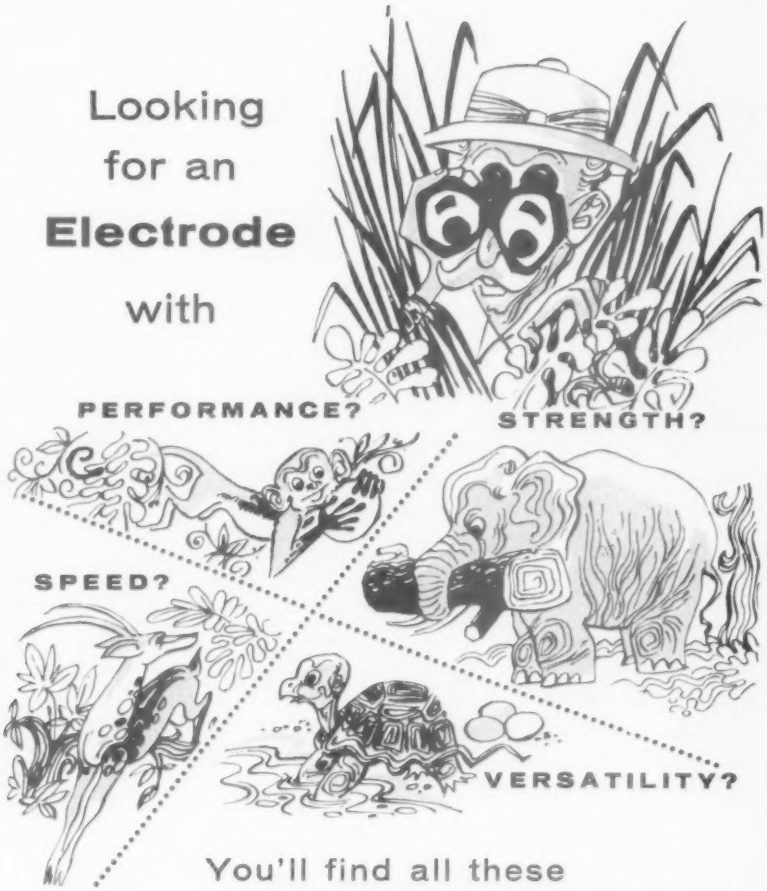
Mr. Rash will make his headquarters in the newly opened Alloy Rods Co. sales office and warehouse at 2201 Dallas Ave., Houston 3, Tex. He is a member of the AMERICAN WELDING SOCIETY.

Carlson Named by Oakite

Edward L. Carlson, advertising manager of Oakite Products, Inc., 19 Rector St., New York 6, N. Y., has been placed in over-all charge of the company's informational efforts in the industrial cleaning and metal finishing fields.

Mr. Carlson, who joined Oakite in 1924 and has served as both copywriter and production manager, was promoted to advertising manager in 1947. In his new capacity he will supervise the company's activities in industrial trade shows and special promotions, as well as trade paper advertising, direct mail, literature and publicity.

Looking for an **Electrode** with



You'll find all these in **CHAMPION'S**

NEW GRAYDAC 13-C ELECTRODE!

(A.W.S. E-6013)

Everything for General Purpose All Position Welding

IT HAS PERFORMANCE! This electrode has a smooth, cushioned arc with real operator appeal. Handles like a dream in any position. Welds are smooth, very finely rippled with slightly convex contour which insures extra strength in fillets. Cleaning is no problem as the slag is self-peeling on many jobs. Spatter is very low.

IT HAS STRENGTH! GRAYDAC 13-C has the following typical excellent mechanical properties:

Yield point	58,000 psi
Tensile Strength	67,000 psi
Elongation in 2"	26%
Reduction of Area	45%

IT HAS SPEED! GRAYDAC 13-C has 5-10% faster burn-off and higher deposition than ordinary E-6013 Electrodes. 3/16" diameter has a burn-off of 10.3"/Minute and deposits 4.2#/Hour at 200 Amperes.

IT HAS VERSATILITY! Try it on railroad car, auto or truck components, structural work, machine parts, farm equipment, stacks, cranes, steel castings, storage tanks, jigs or fixtures, and many many others.

Order a trial lot now from:

THE **CHAMPION** RIVET CO.

Cleveland 5, Ohio • East Chicago, Indiana

For more details, circle No. 23 on Reader Information Card

OBITUARIES

Isaac Harter

Isaac Harter, 77, widely known industrialist, consultant and former vice-president of The Babcock & Wilcox Co. and a director of Vitro Corp. of America, died at his home in New York City on the morning of Thursday, August 22nd.

He was born at Mansfield, Ohio, on Jan. 2, 1880. In 1901, he graduated from the University of Pennsylvania.

Isaac Harter

In the 1920's, Mr. Harter became a director of both The Babcock & Wilcox Co. and the Babcock & Wilcox Tube Co. (now the Tubular Products Division) and as a vice-president of both companies was in charge of their manufacturing operations. He became chairman of the board of the tube company in 1947, and on Apr. 25, 1951, retired from that position to become a consultant to the company.

In the field of welding, Mr. Harter was responsible for broad developments. A good example was his work in applying sound metallurgical principles to the welding of heavy steel plates, often several inches in thickness, to form boiler drums. These had never before been perfectly welded for commercial use. He also successfully demonstrated the application of X-ray to the testing of such welds.

He was active in the group which helped develop the ASME Boiler Code and was instrumental in securing early legislation in Ohio resulting in the Ohio Boiler Code. He helped form the American Uniform Boiler Law Society to secure uniform state laws coordinating the ASME code.

He was vice-president of the AMERICAN WELDING SOCIETY in 1944–45 and was elected a Fellow of the ASME in 1950. He was also a member of the Institute of Metals (London), Sigma Xi and Phi Kappa Sigma. In January 1951, Mr. Harter became the second person ever to receive the Newcomen Medal "for achievement in the field of steam," and held an Honorary Degree of Engineering, Stevens Institute of Technology. His clubs included the University Club and Engineers' Club of New York and the Duquesne Club of Pittsburgh.

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Claude Cornelius Van Nuys

Dr. Claude Cornelius Van Nuys, who until his retirement in 1949 was chief physicist for the Air Reduction Co., Inc., died August 20th at Brea, Calif., following a brain operation. He was 79 years old.

Dr. Van Nuys joined Air Reduction as an engineer in 1918, three years after the incorporation of the company. At the time of his retirement, he was in charge of the physics section of Air Reduction's Research and Engineering Department.

Born Sept. 5, 1878, at Shelbyville, Minn., Dr. Van Nuys was graduated from Yankton College, Yankton, S. D., in 1901. He received a B.A. from the South Dakota School of Mines, Rapid City, S. D., in 1907; an A.M. from Columbia University, New York City, in 1908; and an M.E. from the South Dakota School of Mines in 1909. In 1932, Dr. Van Nuys was awarded an Honorary Sc.D. by Yankton.

Before joining Air Reduction, Dr. Van Nuys was a Professor of Physics and Electrical Engineering at both the South Dakota School of Mines and the Colorado School of Mines at Golden. While with Air Reduction, he obtained many patents for the liquefaction and separation of air and other gas mixtures. He was also the author of numerous articles on the theory of gaseous and liquid mixtures and their separation, thermodynamics of solutions and chemistry of substances.

Alloys and Fluxes for joining ALL METALS ALL METHODS
TORCH WELDING
SOLDERING • FILLING • SEALING
TORCH BRAZING
FURNACE BRAZING
ARC WELDING
WEAR PROBLEM... INSIDE OR OUTSIDE. ONE SOLUTION!
ALL-STATE
NO. 13 NICKEL SILVER BUILDUP ROD
All-State
FLUXES
for welding • brazing • soldering • tinning • cutting
Users Report on Cams: "Using your No. 13 rod to build up such surfaces, we have had 3 to 5 times the cam life."
Users Report on Wrist Pin Holes in 500-lb. Pistons: "No. 13 enabled successful repair where 200 degrees more heat would have spoiled everything. There was no warpage."
For Instruction Book on 62 alloys and fluxes write All-State Welding Alloys Co., Inc. White Plains, N. Y.
ALL-STATE ALLOYS AND FLUXES
REQUEST COMPLETE LIST OF THESE PRODUCTS FOR PROBLEM SOLUTIONS

For more details, circle No. 24 on Reader Information Card

Take Advantage of our

new Reader Information Service

See Page 1059

Why it pays to specify Westinghouse **IGNITRON TUBES,** the "industry standard"

Westinghouse invented and produced the first Ignitron tube. Since then, constant improvements have maintained Westinghouse leadership in the Ignitron field—improvements that are today's accepted industry standards:

- **Kovar seals to permit use of steel envelopes.**
- **Improved Ignitors to insure accurate ignition.**
- **Thermostatic control for overload protection and water savings.**
- **Stainless steel envelopes for corrosion-free long life.**
- **Inner cylinder in direct contact with cooling water.**

The wide acceptance of Westinghouse Ignitron Tubes by the welding industry is proof of their superior quality and performance. It will pay *you* to use Westinghouse Ignitrons in both new and existing welding equipment. For your convenience they are readily available through Westinghouse Distributors everywhere.

YOU CAN BE SURE...IF IT'S

Westinghouse

Electronic Tube Division • Elmira, N. Y.

For more details, circle No. 25 on Reader Information Card

NEW PRODUCTS

Aluminum Fitting

Tube Turns division of National Cylinder Gas Co., Louisville, Ky., recently forged a 24- x 18-in. aluminum tee, barrel-type in appearance, for the new AEC modified "swimming pool" research reactor at Oak Ridge, Tenn. This fitting and the many others made for this project represent the first major use of aluminum for the vital main coolant lines of a nuclear reactor. To

cool the radioactive core, the system will handle a virtual "private river"—12,000 gal of water per min when the reactor is operating at its original design capacity generating 20,000,000 watts of heat. Eighteen-inch lines inside the reactor building are joined into one 24-in. line, which expands into a 36-in. line outside the building. The volume of the 36-in. line, together with a "decay" tank of approximately 10,000-gal capacity, allows the radioactivity in the coolant water from the reactor to be reduced ("decayed") to a safe level before the water is pumped to heat exchangers where it is cooled before being recirculated through the reactor.

For more details, circle No. 26 on Reader Information Card.

Resistance-Welding Power Sources

Two new d-c power supplies for precision resistance welding have been added to the line of welding equipment available from the Commercial Equipment Division, Raytheon Manufacturing Co., Waltham, Mass. Since both power supplies used the stored energy principle, high ratings are achieved with low demand on power lines. The Model 1101 is rated at 2700 watt-sec—equivalent to 470 kva, and the Model 1103 at 8100 watt-sec—equivalent to 2626 kva. According to the manufacturer, high-current density makes possible consistent welds at speeds up to 300 ipm. Metals with high electrical or thermal conductivity can be readily joined. Applications include hermetic weld sealing of transistor cases, precision welding of instruments, relays, vacuum-tube parts, contacts, etc.

For more details, circle No. 27 on Reader Information Card.

Detergent

American Optical Co., Safety Products Division, Southbridge, Mass., has available a newly developed germicidal detergent for factory use in cleaning and sterilizing personal equipment, such as goggles, respirators, face shields and helmets.

It is sold in powdered form in cartons of 25 one-ounce packages. Each package dilutes with a gallon of water. There is no freezing and breakage of containers in storage. A wall-bracket dispenser keeps the detergent dry and dispenses a single package at a time.

For more details, circle No. 28 on Reader Information Card.

Oxyacetylene Torch

The Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y., announces their new W-47 medium-pressure oxyacetylene welding torch.

According to the manufacturer, the Oxweld W-47 torch is capable of welding any metal thickness from 28 gage to

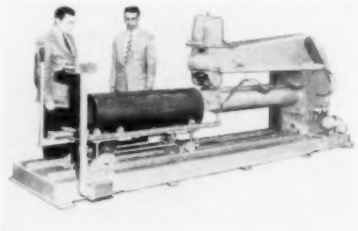
3 in. and handling gas flows up to 1500 sq ft per hr. The torch is also said to handle any oxygen or acetylene flow from 2 to 300 cu ft per hr. Conversion of welding heads will permit either light-duty welding and brazing or heavy-duty welding or heating.

It is also said that each of the 42 welding and heating heads has an additional cartridge-type mixer to assure soft and stable welding flames.

For more details, circle No. 29 on Reader Information Card.

Roll Planishing

A new, automatic weld roll planisher, announced by Airline Welding and Engineering, 785 N. Prairie Ave., Hawthorne, Calif., is especially suited to the manufacture of water heaters, water softeners, containers, tanks, tube and pipe. It cold rolls and flattens flash welds, resistant welds and fusion welds



under controlled pressures up to 10 tons. According to the manufacturer, the Model No. 47560 will receive, planish and eject a 52-in. long shell in 18 sec. The automatic carriage which is readily adjustable to various diameters, receives the shell from the transfer line, carries it into the pressure rolls and ejects it automatically. This roll planishing not only provides a reportedly smoother and stronger weld but also furnishes a smooth, clean surface more suitable for coating with glass, plastic or paint.

For more details, circle No. 30 on Reader Information Card.

All-Position Electrode

A new electrode, Super-SteelTectic 110, with 110,000 psi, for arc welding on mild steels and high strength, low alloyed steels, has been developed by Eutectic Welding Alloys Corporation, 40–40 172nd St., Flushing 58, N. Y.

According to the manufacturer, Super-SteelTectic 110, a universal, all-position, ac-dc alloyed electrode, is especially effective on thin and dissimilar gages with highly critical joints. It is recommended for fabrication of high strength piping and tubing in the flat, horizontal and overhead positions.

The new electrode is said to handle a wide range of jobs. At low amperages, with shallow penetration, it can be used on thin walled tubing, sheet metal and poor fitting joints. At the upper range, it is very effective on structural steel welding of heavy plate, framework, angle and beams.

For more details, circle No. 31 on Reader Information Card.

TO REDUCE WELDING COSTS *JETWELD IT!*

Lincoln Jetweld iron-powder electrodes increase welding speeds as much as 50%. Higher welding currents, greater deposition rate, and self-cleaning characteristics make possible drastic reductions in welding labor costs.

Weld appearance is smoother, approaching the bead quality of an automatic weld.

The Lincoln Jetweld family of iron-powder electrodes is available in four different classifications to meet a wide variety of welding requirements.

E-6024 Jetweld 1 for extra-fast welding of flat and horizontal fillet with AC or DC.

E-6027 Jetweld 2 especially well-suited for deep groove butt welds in the flat position.

E-6016 Jetweld LH-70 for all-position welding of all steels and for welding steels of poor weldability.

E-7020 Jetweld 2-HT . . . for high-tensile deep groove butt welds and fillets in flat position.

For complete information on Jetwelding or the Jetweld electrodes, write for Bulletin SB-1351.

THE LINCOLN ELECTRIC COMPANY

Dept. 1933, Cleveland 17, Ohio

The World's Largest Manufacturer of Arc Welding Equipment

When Jetweld electrodes **Have** higher deposition rates **Yet** give easiest operating qualities

WHY use anything but Jetweld

For more details, circle No. 32 on Reader Information Card

3 BIG REASONS WHY SO MANY WELDERS HAVE SWITCHED TO HI-AMP®
ELECTRODE HOLDERS

1- Wrap around Glass Fibre Tip Insulation—30% more heat resistant than any other make.
2- Brilliant Red Tips and Trigger-Bright Yellow Handle—all Glass Fibre, an outstanding Safety Feature.
3- Body completely insulated—no bare spots.

Just ask your Welding Supply Dealer for PROOF of the above statements.

LENCO, Inc.
JACKSON, MISSOURI
Weld with HI-AMP

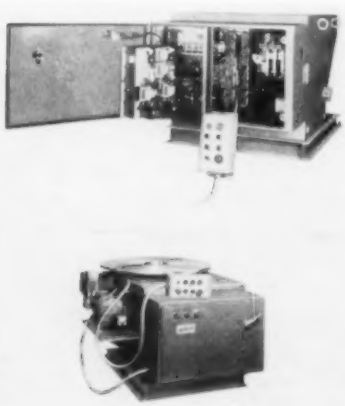
Circle No. 33 on Reader Information Card

Welding Positioner

The Weltronic Co., 19500 W. Eight Mile Rd., Detroit, Mich., engineers and manufacturers of precision welding controls, announce the availability of their Weltronic Heavy Duty Precision Circumferential Weld Positioner Control (EF-7871), built for use with automatic fusion welding machines. It permits operation of a precision welding positioner, providing an uninterrupted circumferential weld.

According to the manufacturer, the motor control contains the following major components: regulated d-c motor control for positioner rotation; a $^1/_2$-hp 203 frame d-c shunt wound motor; an electric clutch-brake for rapid starting and stopping of positioner; a tachometer calibrated in table rpm (dependent on gear box ratio) or calibrated in inches per minute at four table diameters; an accessory panel which includes: (a) an a-c reversing motor starter for table tilt, (b) electric clutch/brake control, and (c) limit switch circuitry to customers' specifications; and the operators control station.

For more details, circle No. 84 on Reader Information Card.



Aluminum Tubing

Aluminum alloy drawn tube, in a wide range of specifications, is now available to industrial users and manufacturers from Kaiser Aluminum & Chemical Sales, Inc., 919 N. Michigan Ave., Chicago 11, Ill.

The company's extrusion plant at Halethorpe, Md., with four draw benches now in operation, is producing round, square and rectangular drawn tube. The round product is available in sizes ranging from $^1/_4$- to $4^1/_2$-in. OD, with wall thicknesses from 0.025 to 0.250 in. depending on alloy and temper. The square and rectangular products encompass a similar size range.

For more details, circle No. 35 on Reader Information Card.

Silver Alloy Flux

Kembs & Company have improved a silver alloy flux for aluminum bronze, beryllium copper, stainless steel, brass, Inconel, nickel and a number of other metals.

According to the manufacturer, this flux melts at 1160° F and its range of efficient action is wide enough to produce good results with higher melting brazing alloys, such as AMS 4772 alloy with a flow point of 1575° F. The wetting action of this flux has been greatly improved. It serves a wide field of applications, including various aircraft work and other processes where longer life is required.

For more details, circle No. 34 on Reader Information Card.

Solder

A flux-cored "solder type" alloy for joining and sealing steels, copper and nickel alloys has been developed by the Eutectic Welding Alloys Corp., Flushing, New York, N. Y.

It is said to be ideal for joining dissimilar combinations of these metals since rapid depositing EutecRod 158-B is a versatile coil form alloy featuring unique fluxing action, excellent tinning ability, and high strength on all metals normally soldered.

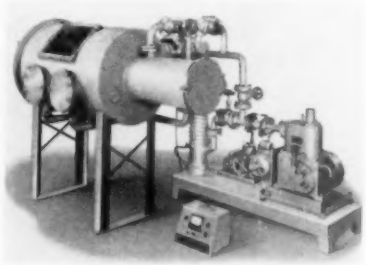
These metals include steel, stainless steel, copper, brass, bronze, Monel and Inconel. Application temperature range is a low 400 to 500° F.

Typical applications for EutecRod 158-B include joining and sealing tanks and containers utilizing Pittsburg seams and other types of mechanical wraps.

For more details, circle No. 36 on Reader Information Card.

Vacuum Chambers

L & B Welding Equipment, Inc., 2424 Sixth St., Berkeley 2, Calif. announces the availability of controlled-atmosphere vacuum chambers capable of ultimate vacuums of better than 10^{-5} mm Hg and available in both standard "packaged" or specialized designs. The chambers are used for research and production welding, casting, and metallurgical research and such metals and alloys as titanium, zirconium, zircalloy-2, hafnium, molybdenum, etc.



Typical of the standard packaged units is the Model VC-32. Unit tank and end bells are of stainless steel; tank capacity is 32 cu ft, with clear inside dimensions of $29^7/_8$ -in. diameter and $54^1/_2$-in. length. Glove and view ports are provided on each side.

For more details, circle No. 37 on Reader Information Card.

NEW TOOL FOR THE TRADE . . .

■ Here is a handy, 24-page guide that will help you pick the right electrode for *any* job! Electrodes are identified by type, AWS grade and color coding, chemical and physical analyses and suggested uses to aid the welding engineer, purchaser, and designer. The M&T Electrode Selector has been called the "handiest practical guide to electrode selection made available in years" . . . And it's yours *free!* *Write Metal & Thermit today for a copy.*

Metal & Thermit MUREX(R) electrodes for mild, low, alloy and stainless steels, aluminum bronze, cast iron, and aluminum; SPEEDEX iron powder electrodes; and HARDEX hard surfacing electrodes are available throughout the U. S.

WELDING SUPPLIES
CERAMIC MATERIALS
ORGANIC COATINGS
TIN & TIN CHEMICALS
PLATING MATERIALS
METALS AND ALLOYS
HEAVY MELTING SCRAP

METAL & THERMIT
CORPORATION
GENERAL OFFICES: RAHWAY, NEW JERSEY

For more details, circle No. 38 on Reader Information Card

Magnet Leech

Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill., announces an accessory for use with Magnaflux and Magnaglo testing operations.

The No. 54975 Leech consists of a permanent alnico magnet, cast steel pole pieces with an aluminum carrying handle, and 5 ft of 2/0 cable. The

manufacturer states it will remain and make electrical contact as long as desired on any magnetic surface, including vertical and overhead members. The magnetizing source may be a-c, d-c, or half-wave current, not exceeding 1500 amp.

The old method of dry powder Magnaflux testing required two men. One man positioned a prod while another applied powder and operated a second prod. The new method frees one inspector for other duties.

For more details, circle No. 39 on Reader Information Card.

Soldering Kit

Smith Welding Equipment Corp., 2633 Fourth St. S. E., Minneapolis 14, Minn., announces their new "Handi-Heet" Soldering Torch Kit.

Designed specially for refrigeration and air-conditioning work, plumbing, auto-repair, etc., lightweight torch can

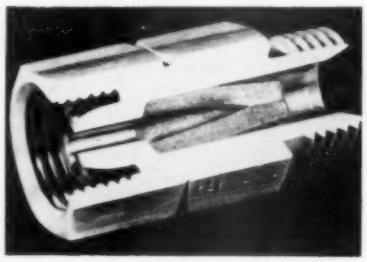
be used for soldering, light brazing, leading, thawing, and many other jobs. Complete units with preset regulator are available to fit commercial tanks, and styles "B," "P.O.L.," and "MC" tanks.

Six tips are reportedly available to handle jobs from delicate jewelry work to fast paint burning, heavy soldering and heating. A soldering iron assembly is also available for soldering seams, connections, splices and general tinwork.

For more details, circle No. 40 on Reader Information Card.

Torch Filter

A torch filter designed to prevent flashback is available from Gibbs Ltd., 3390A Washington St., Boston 30, Mass. The unit consists of an outer



and inner body, each of one-piece construction. The inner body or filter is made of Permetal. The manufacturer states that the connections between the torch and the hose lines can be made with standard tools and that no adapters are needed. The filter is made with either left or right hand threads.

For more details, circle No. 44 on Reader Information Card.

Glass Cleaner

American Optical Co. announces a new combination lens cleaner and antifog fluid, "Super-Clear." The manufacturer states it is the product of ten years of research, and will keep both plastic and glass surfaces fog-free for long periods.

"Super-Clear" can be sprayed on a lens and wiped with either a cloth or goggle cleaning tissue used in many plants. It keeps lenses defogged under extreme conditions, but is nontoxic, noninflammable, and will not deteriorate metal or rubber.

"Super-Clear" is supplied in a two-ounce squeeze-bottle, pint or gallon containers.

For more details, circle No. 41 on Reader Information Card.

EXPLOSION BULGE TESTS

PLATES—WELDS—STRUCTURES

. . . for qualification of materials
. . . . for research and development
. . . . . for weld performance
. . . . . for full-scale tests

Metal Forming by Explosives

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Get the BEST for LESS
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"ANTI-BORAX" FLUXES
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No. 4	"Braz-Cast" Flux for bronze welding cast iron
No. 8	"ABC" Sheet Aluminum Flux
No. 16	Silver Solder Paste Flux

Send for complete Folder and Samples

Mfg. by
ANTI-BORAX COMPOUND CO. INC.
Fort Wayne 9, Indiana

Circle No. 43 on Reader Information Card

Going all over the lot to pick a power source for automatic welding?

Stop!

there's an A. O. Smith welder for every automatic need!

If your present or projected production calls for automatic or semi-automatic welding — here are sound reasons for calling "your man from A. O. Smith." He handles a complete line of power sources to meet any need — a-c, d-c or constant potential for any automatic or semi-automatic process.

He's beholden to no process in particular . . . can thus give you unbiased recommendations.

The broad range of machines he offers enables you to end the "power guessing game" . . . get the right unit to cover all your needs without paying a premium for power you'll never use.

What's more A. O. Smith welders have paced the industry in terms of high-efficiency performance at unusually low cost for maintenance and service.

Enjoy the advantage of a single source for sales and service. Be able to standardize. Simplify both ordering and spare parts stocking. Call your "man from A. O. Smith" now. Ask for Bulletin MW-182.

ALL-PURPOSE a-c WELDER — Model 650E, 650 amp a-c welder for automatic or manual welding. Can be used singly or in series. It's specifically designed for the shop that can't afford to depend on automatic equipment alone.

ALL-PURPOSE d-c WELDER — Model 6000, 600 amp d-c welder for automatic or manual welding. Particularly suitable for A. O. Smith's exclusive C-OMATIC or C-OMANUAL carbon dioxide welding process.

FOR INERT GAS AND SUBMERGED ARC — Model 600CP, full 600 amp constant potential welder. Zero to 45.4 voltage range. Built-in 110 volt power supply — superior voltage regulation.

Through research ...*a better way*

A.O.Smith
CORPORATION
WELDING PRODUCTS DIVISION
Milwaukee 1, Wisconsin
INTERNATIONAL DIVISION: MILWAUKEE 1, WISCONSIN

For more details, circle No. 45 on Reader Information Card

Torch Lighter

Distribution of "Torchie"—a new type of torch lighter, throughout the U. S. and Canada is announced by the Thermacote Co. of California, 108 S. De Lacey St., Pasadena, Calif.

This new product is said to eliminate entirely the need for flint lighters, open flame contacts and the installation

of economizers. According to the manufacturer, it speeds up production in any plant, since all the welder need do is to "swish" his torch within a few inches of the top of "Torchie" and a sure light results.

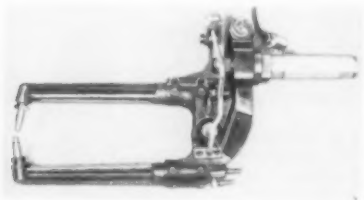
It is equipped with a low voltage transformer (only 7 watts at 2½ volts) and can be plugged into any 110-volt outlet.

For more details, circle No. 46 on Reader Information Card.

Portable Welding Guns

Allied Welder Corp., 8700 Brandt, Dearborn, Mich., announces a new line of portable welding guns.

The cooling of the guns is accomplished by elimination of the usual in-



tegral cast water line. Instead, the incoming water reaches the welding point through a tube that is insulated almost its entire length from the metal of the extension jaw by the return water jacket.

The return water jacket has capacity 5 times that of the in-flow tube and heat transfer to the in-flow tube is much less than with small diameter cast-in return water tubes that build up excessive heat in the jaw extension.

According to the manufacturer, another feature of the new guns is the use of a contact fulcrum pin in place of the conventional shunt that tends to overheat, causing early failure. A built-in guide for the moving jaw prevents wear on the fulcrum pin in event the gun is used in cocked position.

For more details, circle No. 47 on Reader Information Card.

Volt-Ammeter

Pyramid Instrument Corp., Lynbrook, N. Y. has added a new model snap-around volt-ammeter to its Amprobe line—the rotary scale RS-2.

Although it incorporates all the features of the popular RS-1, the new instrument differs from its prototype in that the 600-volt scale has been replaced by a 300-volt scale.

This basic change was reportedly made to provide greater accuracy for the ever-increasing number of appliance servicemen and troubleshooters who work with 220 volts every day.

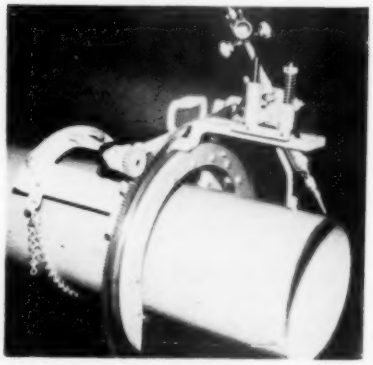
In addition to the 300-volt range, the RS-2 Amprobe has a 150-volt range and four current ranges (5 amp, 15 amp, 40 amp, and 100 amp) each on a separate and distinct scale.

The model RS-2 Amprobe, a pocket size snap-around volt ammeter, comes equipped with a fitted leather case.

For more details, circle No. 48 on Reader Information Card.

Pipe Cutting

H & M Pipe Cutting and Beveling Machine Co. of Tulsa, Okla. has an-

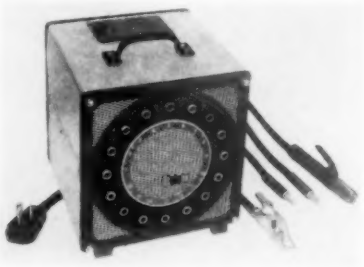


nounced a new and improved design in the "Out-of-Round" attachment for their standard pipe cutting and beveling machines. Working on the spring-tension principle, the spring and a roller rod assembly are the two main components of the attachment. The special attachment is engineered to eliminate the problem of inaccurate cuts or bevels on "out-of-round," or imperfect pipe.

For more details, circle No. 49 on Reader Information Card.

Arc Welder

Brennen, Bucci & Weber, Inc. announce a hand portable industrial arc welder of 200-amp output at 50% duty cycle. Weighing 75 lb the model 200B is fan cooled for production use and it is equipped with a thermal overload switch to prevent transformer



burnout. The manufacturer states that the welder employs a new exclusive ultra-high-efficiency "Transoidal" transformer enabling Model 200B to operate on 110 or 220 volts, and perform the work of a conventional arc welder four to five times its size and weighing three times as much. This unit is said to weld steel 1½ in. thick and will cut steel ¼ in. thick.

For more details, circle No. 50 on Reader Information Card.

Free Information

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Use

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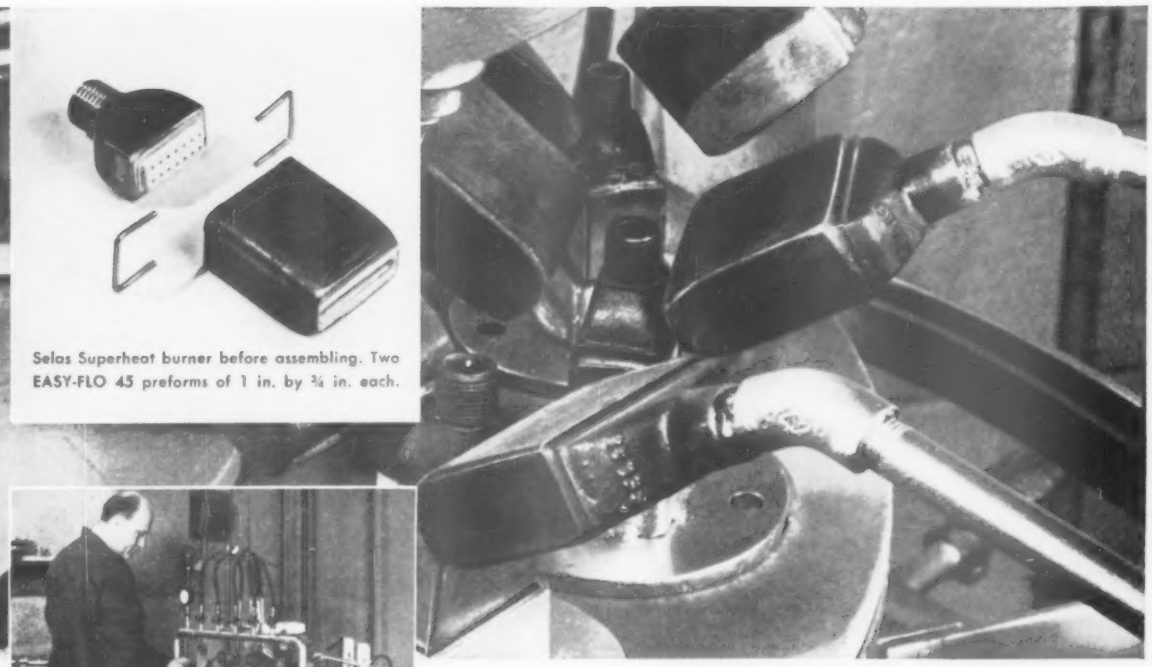
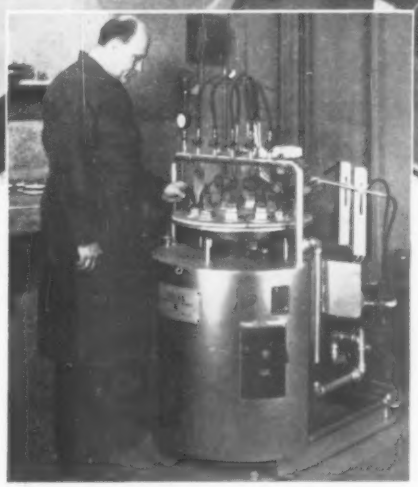


Selas Superheat burner before assembling. Two EASY-FLO 45 preforms of 1 in. by ¾ in. each.



Operator shown placing assembled burners in Selas rotary gas-air equipment to start 75-second brazing cycle. Large illustration shows burners under heat.

JOIN WITH HANDY & HARMAN SILVER BRAZING FOR PERMANENT PROFIT

How Selas Corporation Goes "Full Cycle"... brazing the burners that are used in their brazing machines

If any part of a gas-fired heat processing machine gets more of a workout than the burners, we don't know what it is. It's at this point that high temperatures and heat transfer come to a "head" and if the burner is faulty then the machine is useless. Selas Corporation of America, Dresher, Pennsylvania, custom-builds a large variety of gas-air brazing machines for specific workpiece demands and for their rigid manufacturing requirements they find Handy & Harman silver alloy brazing the *strong* method for joining the metallic components of their superheat burners.

The reputation of Selas heat-processing equipment for precise heating temperatures, specific heat patterns, high heat transfer, speedy change-over and over-all versatility can be attributed in many respects to the burners, which are designed and joined to *bear the brunt* of the machine's work.

Each burner is brazed with two preformed clips of 1/16" Handy & Harman EASY-FLO 45. One machine operator assembles the Inconel burner head to its bronze base, places the preforms, applies the HANDY FLUX and loads the dial conveyor for the brazing cycle. The same operator unloads, cleans and brushes the brazed burners. Each assembly is under heat for 75 seconds and production rate is four per minute. The alloy cost? Three cents per burner. Simple, strong and low cost, we say. You might be able to say the same three things about joining your product. All that's necessary is to call Handy & Harman. We'll tell you everything you want to know about silver alloy brazing – what it is doing for thousands of other products and what it can do for yours.

FIRST, BULLETIN 20

This informative booklet will get you off to a good start on the values, techniques and economies of low-temperature silver brazing. A copy awaits your request.

Your NO. 1 Source of Supply and Authority on Brazing Alloys

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For more details, circle No. 51 on Reader Information Card

NEW LITERATURE

AWS Publications Order Form

The new AWS publications order form for Fall—1957 is now in abundant supply at National Headquarters. This small brochure is an excellent compilation of codes, standards, specifications and books on welding and allied processes. Prices are included.

For your free copy, check box on Reader Information Card.

Standard for Storing Hydrogen

The development of a standard for "the installation of hydrogen storage systems" is being undertaken by the Compressed Gas Association, Inc., according to Franklin R. Fetherston, CGA secretary.

Currently, there is no standard governing such installations, and CGA is preparing the standard because of an expressed industry need, and as the result of recent inquiries by regulatory authorities, and the National Fire Protection Association, International, for recommendations.

Mr. Fetherston stated that the CGA committee which will develop the standard will consist of representatives of hydrogen producing companies, fabricators of storage facilities, manufacturers of valves and fittings and others having an interest.

Gas Delivery

A new illustrated 16-page pamphlet which discusses the bulk delivery method of handling industrial gases in large quantities is now available from Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.

Catalog 450, entitled "Bulk Gas Delivery System," illustrates the several types of delivery units and explains the advantages of each. Diagrams show various plans for trailer-unit parking and indicate the yard space required by each. Typical installations are pictured and unit specifications are tabulated for easy reference.

Related information on control equipment, measurement of gas consumption and distribution pipe lines is also included.

For your free copy, circle No. 52 on Reader Information Card.

Steel Castings

The Tempil® Corp., 132 W. 22nd St., New York 11, N. Y., offers a 52-page reference manual entitled "Recommended Practice for Repair Welding and Fabrication Welding of Steel Castings." This particular manual is a revision of the 1951 edition, both published as a result of research conducted by Battelle Memorial Institute under the sponsorship and general direction of the Steel Foundry Research Foundation. The classification of electrodes by trade name and manufacturer has been expanded from 9 pages in the 1951 edition to 19 pages in the current edition.

For your free copy, circle No. 53 on Reader Information Card.

Stainless Steels

A new 20-page booklet "A Guide to Better Welding of Stainless Steels" has been issued by the Arcos Corp., 1500 S. 50th St., Philadelphia 43, Pa. Intended for both the experienced and less experienced welder, the guide reportedly answers many of the questions that arise in how to get best results. The entire presentation is made in question and answer form. The booklet is illustrated with drawings and closeup photographs to clarify both the problems and solutions.

For your free copy, circle No. 54 on Reader Information Card.

Construction Maintenance

A new 32-page special "Construction Maintenance Issue" of the semi-monthly Technical Information Digest (TIS 2832) is now available from Eutectic Welding Alloys Corp., Flushing 58, N. Y.

Devoted entirely to industry's construction maintenance problems, this special issue is designed to give contractors and their welding maintenance staffs practical weld savings case histories with almost 90 illustrations of the methods utilized.

Welding techniques are explored for virtually every job done in construction and road building fleet maintenance. Particular emphasis is placed on repair of cast iron, manganese and carbon steel, metals most commonly used in hard working construction equipment.

The economy of preventative maintenance through hard surfacing is also treated.

For your free copy, circle No. 55 on Reader Information Card.

Resistance Welding Course

As reported in the September 1957 issue of THE WELDING JOURNAL the Resistance Welder Manufacturers' Assn. had formulated a course on resistance welding through the International Correspondence Schools in Scranton, Pa.

For further details about this course, circle No. 56 on Reader Information Card.

Pipe Fabrication

Engineers, designers and others involved in the fabrication of pipe and tubing will be interested in Bulletin TDC-187, recently released by the Tubular Products Division of The Babcock & Wilcox Co. This six-page folder describes the various methods of bending pipe and tubing and supplies helpful hints which will overcome many of the fabricator's bending problems.

For your free copy, circle No. 57 on Reader Information Card.

Titanium Compounds

A new publication on the physical and thermodynamic properties of titanium compounds has been published by the Office of Naval Research.

This 448-page compendium brings together in one place the existing thermodynamic and physical data (as of Dec. 31, 1954) on compounds of current or potential interest to the extractive metallurgy of titanium.

The book may be purchased for $2.00 from: Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

Structural Welding

A $7\frac{1}{4}$- x $9\frac{3}{4}$-in., 54-page booklet entitled "Welded Structural Details" is available from Publications Dept., British Welding Research Association, 29 Park Crescent, London. W. 1, England.

The booklet concerns structures designed by elastic methods of analysis

Production welding operations are big factor in International Harvester quality control

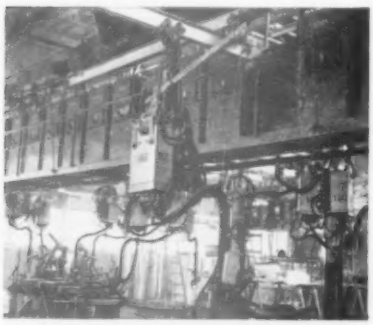
Canadian Plant Uses Robotron Timers on Resistance Welders

Modern production equipment is one of the important reasons behind International Harvester's world famous reputation for quality products. At IH's Chatham, Ontario plant, Robotron resistance welding controls are playing an important part in maintaining this high level of quality in IH trucks for the Canadian market. Robotron precision timers provide efficient, economical control for the scores of resistance welders at work on the company's production line.

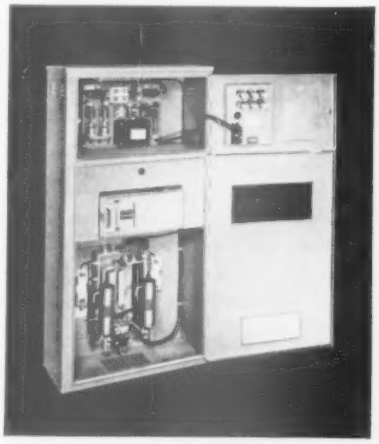
Varied resistance welding problems can be solved with one master unit through interchangeable "plug-in" type components . . . holding costly downtime to a minimum, eliminating equipment tie-ups and reducing obsolescence. The design simplicity of Robotron controls allows maximum on-the-job versatility.

To improve product quality and reduce production costs in *your* operations, let Robotron's experienced staff team up with you in the practical solution of control problems. Discuss your requirements with a Robotron field representative.

Installation of NEMA type N2X Robotron 361C Resistance Welding Controls at International Harvester Plant, Chatham, Ontario. Equipped with 200 amp., 2-pole 600 volt isolation switch, and special Safety-Lock doors.



Another view of installation showing close-up of welding transformers and portable guns.



Series 361C Resistance Welding Control, consisting of Model 3B08E-C NEMA 3B "Fail-safe" tube firing timer, isolation switch, and 600 amp. ignitron contactor.

THE FINEST IN INDUSTRIAL ELECTRONICS

Robotron CORPORATION

21300 WEST EIGHT MILE, DETROIT 19, MICHIGAN

INDUSTRIAL ELECTRONICS FOR YOU...FROM ROBOTRON —A new bulletin available on request. Write for your copy today.

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For more details, circle No. 58 on Reader Information Card

Danny says:

"Airco Easyarc 328 rods mean high speed welding"

The Easyarc 328 electrode is an all position, low hydrogen rod with iron powder added for high welding speeds. The arc action is quiet and spatter loss is low. I recommend it particularly for welding hardenable steels where no preheat is used. It produces very high quality weld metal.

Why not send for the free Airco Electrode Guide which will help you select the right electrode for your specific job. Request catalog 1318.

AIRCO®

AIR REDUCTION SALES COMPANY

A Division of
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150 East 42nd Street, New York 17, N. Y.

Circle No. 59 on Reader Information Card

although many of the details illustrated are suitable for structures designed by the "Plastic Theory."

The relative advantages or limitations of typical details adopted in practice are discussed.

This booklet acts as a guide to the selection of practical details and will assist designers and detail draughtsmen to combine simplicity with performance.

For your copy, send 7s. 6d. to the above organization. Copies will be mailed postpaid.

Automatic Surfacing

The Welding Products Division of Metal & Thermit Corp. of Rahway, N. J. have prepared an information sheet on their five automatic wires for surfacing. Data included are grades, diameters, color codes, hardness, methods of operation, recommended fluxes and applications.

For your free copy, circle No. 60 on Reader Information Card.

Bronze Welding

Revised by Ampco Metal, Inc., 1745 South 38th St., Milwaukee 46, Wis., to include data on the new Ampco-Trode 40 electrode and new Ampco Braz #1, #2 and #3 filler rods, Bulletin W-17 contains up-to-date technical information relative to arc welding with bronze electrodes, filler rod and wire.

Described in the illustrated, 24-page catalog are welding procedure, techniques and processes, recommended welding currents, typical applications and a comprehensive electrode and filler-rod selection and preheat chart.

For your free copy, circle No. 61 on Reader Information Card.

Electrode Cable

Catalog page No. JC-100 describes two types of accessories for welding cable by Tweco Products Co., Boston at Mosley, Wichita 1, Kan.

One accessory called the "Tweco Cable Connection Support" is a formed steel clamp designed to eliminate welding cable strand breakage at the electrode holder connection. The clamp anchors in the electrode holder connection socket and then extends back to encircle and grip the rubber jacket of the cable behind the bare strands. This bridging effect is said to stop the flexing and breakage of the bare strands at this point. The "connection supports" work equally well on either aluminum or copper cable.

The other accessory known as "Jacket Grippers" is designed to eliminate jacket slippage in welding cable. These lapped-end steel bands are said to bind the cable strands and cable jacket into a strong composite section. In addition, they can be attached at any point in the welding circuit. The "jacket grippers" are made in four sizes to cover the full range of welding cable.

For your free copy, circle No. 62 on Reader Information Card.

Resistance Welding

Edition No. 576 of "Weld-It," the publication of the Taylor-Winfield Corp. of Warren, Ohio, is now available.

Described is an arc welder for continuous strip operations which is capable of shearing and welding strip materials to a maximum of 0.090 in. thick by 8.5 in. wide. Also included is an illustrated article on resistance welding operations at the Convair plant in San Diego.

For your free copy, circle No. 63 on Reader Information Card.

Grinding Wheels

The American Standards Association, on March 7, 1957, approved the American Standard *Identification Code for Diamond Wheel Shapes*. Printed copies of this standard have just been made available for distribution to industry.

The foreword of this publication points out that "the growth of the diamond wheel industry has been rapid. It has also become increasingly complex in that a great diversity of shapes is required to perform operations which had not been considered suitable diamond wheel applications only a few years ago.

"As a result the old system of coding the shape types of diamond wheels had become outmoded and unapplicable. Attempts to work within the system already in most common use and to extend that system met with failure. It was impossible to devise a suitable modification of the old system without the fault that one symbol could mean two or more different things under varying conditions.

"To correct this situation, the committee within the industry studied the problem, determined the necessary characteristics for clear description and established a coding system within that framework. By using the system as listed in this new American Standard, every conceivable shape of diamond wheel can now be typed by the use of the symbols set forth therein."

Single copies of the standard are available free of charge by request on company letterhead from the Grinding Wheel Institute, 2130 Keith Building, Cleveland 15, Ohio.

For more details, circle no. 64 on Reader Information Card →

USS TECHNICAL WELDING DATA

4

Weld Metal Properties

As an aid to the engineer and designer, here are the properties of weld metal deposited by a few types of available electrodes. Other very good types of electrodes are now on the market.

TYPICAL CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF WELD METALS DEPOSITED BY HIGH STRENGTH ELECTRODES

AWS Class	Comp. Type	Weld-metal composition, % (undiluted deposit)										
		C	Mn	P	S	Si	Ni	Cr	Mo	V	Cu	Ti
E9015	Mn-Mo	0.07	1.45	0.025	0.024	0.39	0.06	0.08	0.35	0.02	0.14	0.013
E11016	Mn-Ni-Mo	0.08	1.02	0.015	0.030	0.28	3.73	0.01	0.63	0.005	0.11	0.014
E12015	Ni-Mo-V	0.06	1.12	0.011	0.018	0.40	2.11	0.11	0.95	0.21	0.11	0.005

AWS Class	Comp. Type	Condition	All-weld-metal tensile properties (0.505" diam. specimen)				
			Interpass Temp., °F.	Yield Strength (0.2% Offset), psi	Tensile Strength, psi	Elong. in 2 in., %	Red. of area, %
E9015	Mn-Mo	As-welded	100	88,800	95,700	16.3	28.1
E9015	Mn-Mo	As-welded	Rising	61,750	84,600	29.0	62.5
E9015	Mn-Mo	Stress-relieved (1100°F.)	100	87,250	94,200	23.5	55.7
E9015	Mn-Mo	Stress-relieved (1100°F.)	Rising	67,500	82,500	26.8	63.1
E11016	Mn-Ni-Mo	As-welded	100	119,300	124,400	18.5	54.5
E11016	Mn-Ni-Mo	Stress-relieved (1100°F.)	100	106,200	113,400	21.2	58.6
E12015	Ni-Mo-V	As-welded	100	113,300	129,200	20.5	58.7
E12015	Ni-Mo-V	Stress-relieved (1100°F.)	100	116,000	128,700	18.8	59.4

AWS Class	Charpy-keyhole impact properties		
	Comp. Type	Condition	Ductility-transition Temp., °F.
E9015	Mn-Mo	As-welded	minus 155
E9015	Mn-Mo	Stress-relieved (1100°F.)	minus 83
E11016	Mn-Ni-Mo	As-welded	minus 166
E11016	Mn-Ni-Mo	Stress-relieved (1100°F.)	minus 90
E12015	Ni-Mo-V	As-welded	minus 78
E12015	Ni-Mo-V	Stress-relieved (1100°F.)	above 130
E12015	Ni-Mo-V	Quenched from 1675°F., tempered at 1175°F.	45 above zero

NOTE: Weld metals deposited by such electrodes on USS "T-1" Steel would have their chemical compositions altered by admixing of elements from the steel, and their yield and ultimate strengths would be increased.

REMEMBER THIS: No other alloy steel offers the combination of properties that "T-1" Steel possesses. Here, in just one steel, you get very high yield strength (90,000 psi minimum), extraordinary toughness, great resistance to impact abrasion, and good high temperature strength. These let you reduce the size of highly stressed parts . . . save weight, reduce the amount of welding required and cut your costs. USS "T-1" Steel is being used in bridges, excavating equipment, pressure vessels, towers . . . in equipment that must take heavy abuse in sub-freezing temperatures . . . in equipment that must withstand heavy stresses and impact abrasion at temperatures up to 900°F.

WRITE FOR COMPLETE INFORMATION about the application and fabrication of USS "T-1" Steel. United States Steel, Room 2801, 525 William Penn Place, Pittsburgh 30, Pa.

USS "T-1" CONSTRUCTIONAL ALLOY STEEL

"USS" and "T-1" are registered trademarks.

United States Steel Corporation, Pittsburgh • Columbia-Geneva Steel Division, San Francisco • Tennessee Coal & Iron Division, Fairfield, Ala.
United States Steel Supply Division, Warehouse Distributors, Coast-to-Coast • United States Steel Export Company, New York

UNITED STATES STEEL

Aluminum cranes are now being welded using semiautomatic equipment.

New Alcoa welding alloy makes possible the aluminum crane

For a long time, the idea of an aluminum crane has interested designers. Much lighter in weight, it would permit lower cost building foundations or a higher capacity crane on the same foundations. But how to make it? Riveted construction is outmoded and expensive.

Now aluminum cranes are being built, thanks to a new Alcoa alloy. Designated 5456, this new alloy has the highest as-welded strength of any commercial aluminum alloy yet developed. Guaranteed minimum properties are 42,000 psi ultimate and 19,000 psi yield on the plate and equally good ultimate strength across the weld.

Using the new alloy and the inert-gas consumable-electrode process, it costs no more to fabricate aluminum cranes than steel cranes. There are long welding runs involved, up to 60 feet, and semiautomatic equipment is used. Speeds as high as 80″ per minute are achieved.

In addition to their light weight, these aluminum cranes can be used in corrosive atmospheres and will require no painting.

Alcoa is headquarters for fresh and exciting ideas like this on how to weld, braze or solder aluminum. Get in touch with an Alcoa distributor listed at right. And write now for booklets and films that show how easy it is to weld, braze and solder aluminum. Aluminum Company of America, 1741-K. Alcoa Building, Pittsburgh 19, Pa.

NEW! "ALCOA THEATRE"
Exciting Adventure, Alternate Monday Evenings

ALCOA ALUMINUM
WELDING PRODUCTS
ALUMINUM COMPANY OF AMERICA

Your Guide to the Best in Aluminum Value

For more details, circle No. 65 on Reader Information Card

Want technical help in welding, brazing or soldering aluminum? Contact your Alcoa sales office, listed under "Aluminum" in the Yellow Pages of your phone book.

For immediate delivery of Alcoa welding products, call your Alcoa outlet listed below. He carries a complete range of alloys and sizes.

ALABAMA
Birmingham
Hinkle Supply Co.
CALIFORNIA
Los Angeles
Ducommun Metals & Supply Co.
Pacific Metals Company, Ltd.
San Francisco
Pacific Metals Company, Ltd.
COLORADO
Denver
Metal Goods Corp.
FLORIDA
Jacksonville
J. M. Tull Metal & Supply Co., Inc.
Miami
J. M. Tull Metal & Supply Co., Inc.
Tampa
J. M. Tull Metal & Supply Co., Inc.
GEORGIA
Atlanta
J. M. Tull Metal & Supply Co., Inc.
Southern Oxygen Co.
ILLINOIS
Chicago
Machinery & Welder Corp.
Steel Sales Corp.
Moline
Machinery & Welder Corp.
KENTUCKY
Louisville
Williams and Co., Inc.
LOUISIANA
New Orleans
Metal Goods Corp.
MARYLAND
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Southern Oxygen Co.
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MASSACHUSETTS
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NEW HAMPSHIRE
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Edgcomb Steel of New England, Inc.
NEW JERSEY
Harrison
Whitehead Metal Products Co., Inc.
Merchantville
Southern Oxygen Co.
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NEW YORK
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Whitehead Metal Products Co., Inc.
New York
Southern Oxygen Co.
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Syracuse
Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.
NORTH CAROLINA
Asheville
Southern Oxygen Co.
Charlotte
Southern Oxygen Co.
Greensboro
Southern Oxygen Co.
Raleigh
Southern Oxygen Co.
OHIO
Cincinnati
Williams and Co., Inc.
Cleveland
Nottingham Steel & Aluminum Co.
Williams and Co., Inc.
Columbus
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Toledo
Williams and Co., Inc.
OKLAHOMA
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Metal Goods Corp.
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Whitehead Metal Products Co., Inc.
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York
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Southern Oxygen Co.
Knoxville
Southern Oxygen Co.
TEXAS
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Metal Goods Corp.
Houston
Metal Goods Corp.
UTAH
Salt Lake City
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VIRGINIA
Arlington
Southern Oxygen Co.
Charlottesville
Southern Oxygen Co.
Lynchburg
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Norfolk
Southern Oxygen Co.
Richmond
Southern Oxygen Co.
Roanoke
Southern Oxygen Co.
WASHINGTON
Seattle
Pacific Metal Co.
WEST VIRGINIA
Bluefield
Southern Oxygen Co.
WISCONSIN
Milwaukee
Machinery & Welder Corp.

Surface Equipment

New types of Challenge Machinery Co.'s precision surface equipment for tooling and production operations in metalworking and welding shops is described in catalog folder No. 823. Included are complete information on the new three-point-suspension surface plates, magnesium and semi-steel straight edges and parallel straight edges and dove-tailed straight edges. The Challenge Machinery Co. is located in Grand Haven, Mich.

For your free copy, circle No. 66 on Reader Information Card.

Aluminum

The Aluminium Development Association, 33, Grosvenor St., London, W. 1, England, announces the availability of two information bulletins on aluminum.

Bulletin No. 22 entitled "The Brazing of Aluminium and Its Alloys," compares the principal brazing methods. Tabulations and data are listed for various aluminum properties. Choice of brazing methods and properties of brazed joints are also discussed.

For your copy of Bulletin No. 22, send 2s. to the above address.

An addendum to Bulletin No. 19 entitled "Recommendations for the Testing of Aluminium Fusion Welds," the first section deals with nondestructive and destructive testing methods. The second section describes the making of test welds. Finally, a list of defects distinguishes between negligence of the welder and defects inherent to the process itself.

For your free copy, circle No. 67 on Reader Information Card.

Gas Burners

The Selas Corp. of America, Dresher, Pa., announces publication of Bulletin S-1054. The literature states that "Selas Superheat Burners" produce high heat release to localized areas of workpieces, extending the possibilities and increasing the effectiveness of selective open heating for flame hardening, flame annealing, brazing and soldering, heating for hot working, preheating, spot-heating and flash cleaning.

The manufacturer claims that superheat burners use only commercial fuel gas and air—with no bottled oxygen. Gas and air are burned under pressure to produce flame temperatures up to 3000° F and blast velocities to 2500 ft/sec.

For your free copy, circle No. 68 on Reader Information Card.

Safety Data on Acetylene

Publication of a revised safety data sheet on acetylene (SD-7) has been announced by the Manufacturing Chemists' Association, Inc., Washington, D. C.

The 11-page booklet is part of a continuing MCA series on safety data sheets. It has been updated from the original 1947 publication and includes a recommended label for cylinders containing acetylene.

Presented also are sections on properties, hazards, engineering control, employee safety, fire fighting, handling and storage, tank equipment cleaning and repairs, medical management and first aid.

Copies of Chemical Safety Data Sheet SD-7, Acetylene, may be obtained at 30 cents each from the Manufacturing Chemists' Association, Inc., 1625 Eye St., Northwest, Washington 6, D. C.

Safety Equipment

New catalog 10, just published by the General Scientific Equipment Co., 7516 Limekiln Pike, Philadelphia 50, Pa., presents the company's entire line of safety equipment in an easy-to-use buyers'-guide arrangement.

The catalog includes all types of protective equipment—from a small half-ounce dust mask to a large barrel lifter.

Nearly all of the several hundred listed items are illustrated; general specifications and recommended uses are given for each.

Equipment is grouped according to its function so that the reader can compare similar products and select the ones best suited to his needs. Product descriptions are completely factual and sufficiently detailed to permit a proper choice.

For your free copy, circle No. 69 on Reader Information Card.

Spot Welding

Eisler Engineering Co., Inc., 750 S. 13th St., Newark 3, N. J., announces a catalog which illustrates and describes the products manufactured and supplied by them. The "New Small Spot Welder Catalog" contains 16 pages and is devoted primarily to resistance spot and butt welders.

For your free copy, circle No. 70 on Reader Information Card.

Aluminum and Surfacing

Two new technical bulletins are available from Eutectic Welding Alloys Corporation, Flushing 58, N. Y.

Bulletin TIS 2813 entitled "Low Heat Input," 6 pages, discusses metal joining and repair problems peculiar to aluminum. Welding rod and electrode characteristics on all types of aluminum are given. Procedures are given to overcome such conditions as warping, distortion, cracking and embrittlement.

Bulletin TIS2821 entitled "Hard Surfacing Maintenance—Industry's Economy Weapon," 20 pages, discusses wear and the need for overlays for abrasion, corrosion, friction, heat and impact. Contained in the bulletin are 57 photographs illustrating various hard-surfacing applications and procedures. Case histories from the field are also presented. Surfacing is discussed in its relation to the tool room, mines, railroads and earth moving equipment.

For your free copies, circle No. 71 on Reader Information Card.

Brazing Fundamentals

Progress in the improvement of brazing techniques and technology is reviewed in a report of Army-sponsored research into the fundamentals of the art just made available to industry through the Office of Technical Services, U. S. Department of Commerce. Two reports of previous work on the project, released earlier through OTS, also are available.

The third year of research, from June 1954 to June 1955, was concerned with two fundamental problems: the mechanism of the formation of the metallic bond in a brazed joint; and correlation between the bonding mechanism and the strength of brazed joints. Study on the first problem resulted in proof that the most characteristic process in the formation of the metallic bond in brazed joints is an extremely fast saturation of the molten filler metal by the base metal during the filling period of the capillary gap and subsequent precipitation of the base metal dendrites on the base metal-filler metal interface during cooling.

Extensive studies on the correlation between bonding mechanism and strength concluded that brazing temperature can considerably alter the structure of a joint but not the tensile strength. A new shear testing device was developed to investigate shear strengths of silver brazed and copper brazed joints in drill rod. The device was thought to be superior to existing tests.

The report, PB 121553 *Fundamentals of Brazing*, N. Bredzs and H. Schwartzbart, Armour Research Foundation for U. S. Army Ordnance, December 1955, may be ordered from OTS, U. S. Department of Commerce, Washington 25. It contains 101 pages, price $2.75. The two earlier reports, both bearing the same title, are: PB 111697, December 1954, 162 pages, $4.25; and PB 111509, December 1953, 114 pages, $3.50.

Ceramics

Bulletin 108, a 5-page report on Sur-Braze S-2 casting ceramic, a new ceramic used for high-temperature tooling to 3000° F, is now available from the Duramic Products Div., Technion Design & Mfg. Co., Inc., 262–72 Mott St., New York 12, N. Y.

Bulletin 108 includes technical data such as density, thermal expansion, firing shrinkages. . .along with a photo showing the casting method, and report on firing procedures, design considerations and applications, for Sur-Braze S-2 ceramic.

Sur-Braze S-2 casting ceramic is now being applied to high temperature tooling, such as brazing, welding fixtures, sintering and glass firing boats, heat-treating jigs and stress-relieving fixtures. It is available in raw powders for customer fabrication or as special molded parts.

For your free copy, circle No. 73 on Reader Information Card.

Grinding Wheels

The United States Department of Commerce, on July 1, 1957, approved for promulgation the new revised *Grinding Wheel Simplified Practice Recommendation* R45-57.

This new 76-page edition supersedes the former 1947 edition and includes many major changes and improvements.

Single copies of the Recommendation are available free of charge, by request on company letterhead, from the Grinding Wheel Institute, 2130 Keith Building, Cleveland 15, Ohio.

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For more details, circle No. 72 on Reader Information Card

Stud Welding Manual

According to the manufacturer, all the information needed to obtain best results, at lowest cost, in detailing and specifying Nelson standard end-welding studs is included in a new 38-page manual, Stud Specifications, now available from the Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

Included are dimensions of the standard studs and ferrules, size of weld fillets, available types of plating, annealing and flux, and analyses and mechanical properties of stud materials.

For your free copy, circle No. 74 on Reader Information Card.

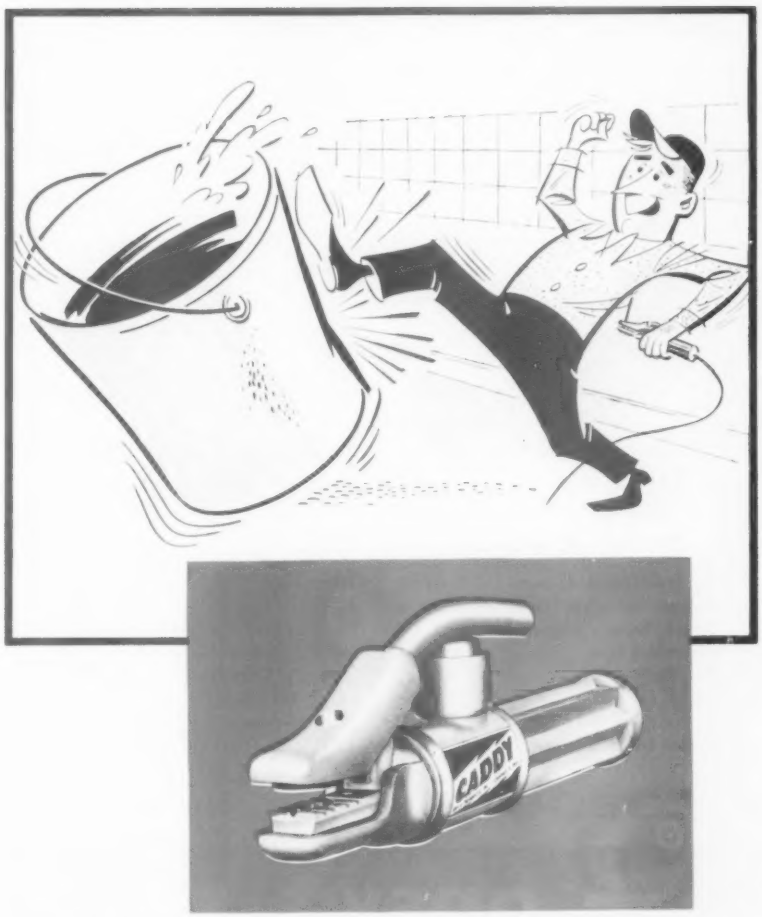
Stainless-Steel and Titanium Structures

A summary of available information on stainless-steel and titanium sandwich structures has been issued by the Titanium Metallurgical Laboratory at Battelle Institute, Columbus, Ohio.

Research in various laboratories has been directed toward development of sandwiches that remain structurally sound at elevated temperatures, the report states. Such structures are of interest because of their high strength-to-weight ratios.

Brazed stainless-steel sandwiches with a honeycomb-type core have been fabricated in flat and curved panels that are used in the heat-treated condition. They have comparatively high strength-to-weight ratios in the temperature range from 600 to 900° F. However, there are still a number of problems that must be overcome before stainless-steel sandwich structures can be fully utilized. Among these are the need to reduce the amount of hand labor required to fabricate the panels and to improve joining methods. The summary report includes a discussion of fabrication techniques used to produce sandwich structures and methods of evaluating them. Sections are also included on the development work under way in various laboratories on sandwich structures.

Authors of the TML report are W. J. Lewis, G. E. Faulkner, and P. J. Rieppel, of Battelle. The Titanium Metallurgical Laboratory is supported by the Air Research and Development Command on behalf of the Department of Defense and in cooperation with the Army and Navy. Copies of the current report are available to Defense contractors or subcontractors from the Titanium Metallurgical Laboratory, Battelle Institute, Columbus, Ohio, and others may purchase copies from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.



WELDERS all over are "Kicking the Bucket"

NO, the death rate isn't increasing. The welders are switching to CADDY Electrode Holders. The two holder, one in the bucket, system is gone.

CADDY Holders run cool, because the normal high resistance hot spot of a mechanical connection is replaced with the 100% efficient CADWELD Connection. If your plant hasn't tried CADDY Electrode Holders – let us know – we'll be glad to make a CADDY demonstration.

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2070 E. 61st Place · Cleveland 3, Ohio
IN CANADA: ERICO INCORPORATED, 3571 Dundas St., West, Toronto 9, Ontario

For more details, circle No. 75 on Reader Information Card

Toggle Clamp

The Detroit Stamping Co., 322 Midland Ave., Detroit 3, Mich., announces release of bulletin 105, literature describing four new "tiny toggles," the manufacturer's designation for these toggle clamps.

The four models are illustrated: 105-UB (upper left); 105-U (upper right); 105-SB (lower left); and 105-S (lower right). The "U" and "UB" models both have U-bars for holding adjustment spindles, but "U" has a horizontal base, whereas the "UB" has a vertical base.

The "tiny toggles" are reportedly $^{3}/_{4}$ in. high and $2^{3}/_{4}$ in. long when closed.

For your free copy, circle No. 76 on Reader Information Card.

Heating Element

The Globar Division of The Carborundum Co. announces a new Delta silicon carbide heating element.

All silicon carbide heating elements increase in resistance with use. The Delta element, however, reportedly builds up resistance at a very gradual and extremely uniform rate, which results in longer element service, lower replacement costs, more uniform product quality and greater continuity of production. Technical bulletin "H" describes element in more detail.

For your free copy, circle No. 77 on Reader Information Card.

Burnishing Compound

Oakite FM 103, the company's latest barrel finishing material, is the subject of service report B-6644, recently published by Oakite Products, Inc., 118 E. Rector St. New York 6, N. Y.

According to the manufacturer, Oakite FM 103 is specially compounded to improve brightness of work and to develop exceptional color and luster on brass, copper, nickel-silver, gold, and mild and hardened steel parts.

For your free copy, circle No. 79 on Reader Information Card.

REVIEWS
OF NEW BOOKS

Plant Maintenance

Techniques of Plant Maintenance and Engineering, the proceedings of the Technical Sessions held concurrently with the Eighth National Plant Maintenance and Engineering Show in Cleveland in January 1957. Copies of the 1957 edition @ $10.00 per copy from Clapp & Poliak, Inc., 341 Madison Ave., New York 17, N. Y.

This $8^{1}/_{2}$ by 11-in. book is a record of the discussions held at the show. It includes both the prepared papers and the informal extemporaneous question-and-answer sessions that followed them.

Eight pages are devoted to a paper entitled "Maintenance Welding." A discussion is included. Papers and discussions entitled "Metal-working Plants," "Steel Mills," "Metal-fabricating Plants" and "Foundries," to mention a few, are also included.

3 answers . . .
TO MAINTENANCE
WELDING PROBLEMS

MANGANAL FLO-KOTE (HEAVY COATED, AC-DC)
MANGANAL SPECIAL TITE-KOTE (LIGHT COATED, AC-DC)
MANGANAL BARE (UNCOATED, DC ONLY)

11% — 13½% MANGANESE - NICKEL STEEL
WELDING ELECTRODES

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With BS or MS degrees. One position is for a recent graduate. The other is for a man up to 35, with experience in the application of metallurgy to production problems.

Work in applied research, dealing with welding ferrous and non-ferrous alloys, investigation of service problems, and selection of materials of construction.

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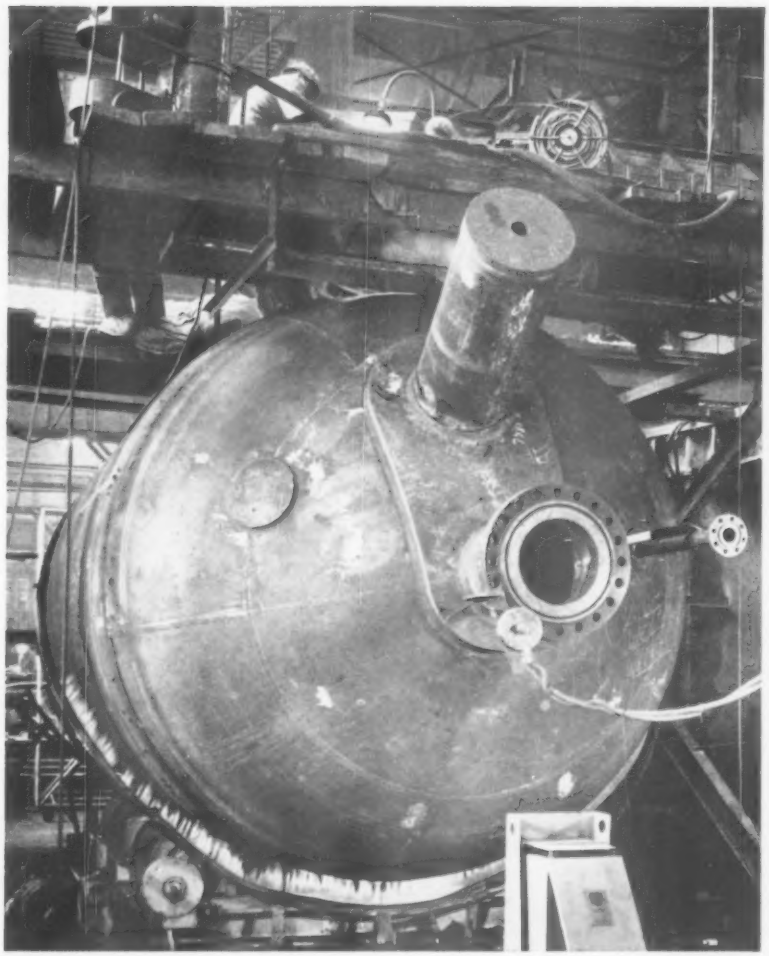

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Stainless Steel Welding Wire

In hundreds of applications, *Drawalloy* wire has been put to the test . . . X-ray, dye check, pressure and service and with the same consistent result—OK as welded. That's why Frank Iapalucci, Manager of Welding Engineering for Baldwin Lima Hamilton, Eddystone, Penna., selected *Drawalloy* chrome-moly wire for the automatic welds on this reactor. The vessel is constructed of A 301-54T Grade B firebox quality steel ranging in thickness from 5-1/16″ to 2-5/8″. *Drawalloy* 1-1/4 Cr, 1/2 Mo wire was used for all submerged arc joints.

When inspection by X-ray is required, don't gamble . . . rewelding is expensive . . . specify Drawalloy "quality controlled" wire. *Drawalloy* stainless steel welding wire is produced to strictly controlled specifications to provide the right chemistry, finish and temper for smooth operation in your equipment and to provide X-ray quality welds.

Why not discuss your stainless welding wire needs with your *Drawalloy* Distributor or Representative . . . a man ready to help you. Bulletin 355-DC provides complete information on every grade of *Drawalloy* wire. Write to: Drawalloy Corporation, Lincoln Highway West at Alloy Street, York 13, Pennsylvania.

DRAWALLOY
CORPORATION
YORK, PENNSYLVANIA

THE WIRE MILL FOR THE WELDING INDUSTRY — STAINLESS STEEL · HARD SURFACING · TOOL STEEL

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TEMPILSTIK° marks on workpiece "say when" by melting at stated temperatures — plus or minus 1%.

ALSO AVAILABLE IN LIQUID AND PELLET FORM . . . WRITE "WELDING SALES" DEPT. FOR SAMPLE TEMPIL° PELLETS . . . STATE TEMPERATURES OF INTEREST—PLEASE!

Available in these Temperatures (F.)

113	375	1000
125	388	1050
138	400	1100
150	413	1150
163	425	1200
175	438	1250
188	450	1300
200	463	1350
213	475	1400
225	488	1450
238	500	1500
250	550	1550
263	600	1600
275	650	1650
288	700	1700
300	750	1750
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STRESS RELIEVING OF WELDMENTS

WRC- sponsored report summarizes the knowledge concerning the origin, nature and effect of residual stresses and the influences of thermal and mechanical stress-relieving treatments on the service performance of welded structures

BY EARL R. PARKER

SUMMARY. Residual stresses are those present in a solid body when no external forces are acting upon the body or they may be considered as the stresses that remain in a structure as result of localized plastic deformation. Residual stresses introduced by welding are caused by localized heating associated with the welding process and to a lesser degree by shrinkage of the weld metal. Such residual stresses may be large in magnitude, frequently reaching the yield point of the material. In some instances they have been directly responsible for the fracturing of welded assemblies.

In a butt weld of unrestrained flat plates the residual stress in the direction parallel to the weld generally is much greater than in the direction transverse to the weld, although transverse stresses may approach the yield point in large thick plates joined by multipass welds.

The relation of residual stress to brittle fracture is still a matter of controversy but experimental evidence appears to indicate that residual stresses have little effect unless defects such as a crack are present.

Reaction stresses occur in structures that are welded under restrained conditions. "Residual stresses" are generally considered to be highly localized and associated with steep stress gradients as distinguished from "reaction stresses" which are uniform over relatively long distances. Reaction stresses can be relaxed by separating two parts of a structure by a single cut whereas residual stresses cannot. Reaction stresses in welded parts can initiate brittle fracture.

Residual compressive stresses are considered to improve fatigue life but it has not been proved that residual tensile stresses are deleterious. Limited evidence indicates that ordinarily welding stresses have little effect on fatigue behavior.

Although reports of fractures in service due to welding stresses are rare, such failures that have occurred have indicated that residual stresses in conjunction with other factors such as low temperature, thermal stresses, excessive cold work and mechanical defects can be a contributing factor.

Welding stresses may be relieved by either of two basic methods: by thermal stress relieving or by mechanical stretching. Thermal treatment is a very effective means for removing welding stresses. Mechanical stress relieving is accomplished by stretching plastically the regions that are under tension. A variation of this process is "low-temperature stress relieving" which involves heating two bands adjacent to and parallel with the weld to a controlled low temperature (about 350° F). This process is finding considerable use on large simple structures.

A number of factors influence the relief of residual stress. Among these are (1) initial stress level, (2) time, (3) temperature, (4) composition of steel and (5) microstructure. Section size is also important because it determines the length of soaking time required to insure that all parts of a structure are thoroughly heated. Preheat also influences the residual stress pattern and hence the stress-relieving process.

Introduction

The thermal effects incident to welding introduce residual stresses into weldments. The patterns of residual stress vary with the welding conditions, as a number of investigations have shown. Residual stresses are like any other stress and add to the component of load stress acting in the same direction. (This is true, of course, only when the total strain is elastic.) The nature of residual welding stress is well understood; so too are the procedures used for removing such stress. The greatest uncertainty (and this is a subject of current and often heated debate) is the influence that internal residual stresses have on service performance. If they have no effect, then why stress relieve weldments? If they do affect service performance, then how do they act? These are important questions which seemingly should have simple answers. Unfortunately, the story is not so straightforward. The answers are beclouded with an assortment of controversial facts and questionable information.

Engineers pressed for decisions about the need for stress relieving generally find their problems answered for them in the "codes" which regulate the design and construction of welded structures. Codes are the governing rules that have been established by groups of experienced engineers to define the maximum working stresses and the minimum construction requirements considered necessary for satisfactory service at the time the rules were established. Unfortunately, however, there are many cases not covered by the codes. In such cases, an engineer must rely upon his own experience for details of design and for construction procedures. It behooves those confronted with such problems to become familiar with the

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available facts about residual stresses. It is the purpose of this report to summarize the knowledge concerning the origin, nature, and effect of residual stresses and the influences of thermal and mechanical stress-relieving treatments on the service performance of welded structures.

Residual Stresses

Residual stresses are defined as those stresses present in a solid body when no external forces are acting on the body. Such stresses combine with load stresses in an additive manner, providing the total stress remains below the elastic limit of the material. In any event, the *strains* produced by residual stresses and those produced by external loads are generally additive, even for strains several times as high as those at the elastic limit.

Residual stresses introduced by welding may be large in magnitude, frequently reaching the yield stress of the material. Residual welding stresses are troublesome and in certain instances have been directly responsible for the fracturing of welded assemblies. More will be said about this phase of the problem in the next section of this report.

Welding stresses are not entirely caused by the shrinkage of the weld metal, as is sometimes believed. In fact, stresses of the same magnitude and distribution can be introduced in a plate or structure by heat alone without any welding at all. For example, if a spot on a plate of steel is heated rapidly to about 400° F, either with an acetylene torch or by an electric current, radial tensile stresses of yield point magnitude will exist in the plate after it cools to room temperature.

Steep temperature gradients introduced by local heating are primarily responsible for residual welding stresses. Consideration of the behavior of a heated spot will help to clarify this statement. A heated spot tends to expand while the surrounding metal remains cool; the heated volume thus becomes too large to fit into the space it formerly occupied. Expansion in the plane of the plate, however, is restricted by the surrounding cold material and so biaxial compressive stresses are developed in the heated metal. The hotter the spot is heated, the higher the stress level becomes. If heating continues, the stress will rise to the yield point of the steel and then the heated metal will begin to flow plastically or buckle, depending on the thickness. In the absence of buckling, restraint in the plane of the plate restricts lateral flow and all of the plastic deformation is confined to the thickness direction; thus the plate becomes permanently thicker in the region of the heated spot. When the metal has cooled and again resumes

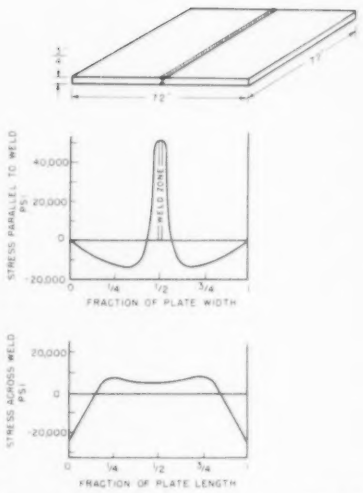

Fig. 1 Pattern of stress developed by butt welding of two plates

a uniform temperature, the upset spot tends to remain thicker and smaller in diameter than it originally was. Since the total volume of metal must remain constant, the thickened portion no longer fits normally into the space it formerly occupied. The upset spot must therefore be stretched to maintain continuity with the remainder of the plate. This stretching induces radial residual tensile stresses in the plate at the locus of heating.

As a second example, the effect of locally heating one edge of a thick plate to a temperature of about 400° F will be considered. Such heating can be accomplished with an acetylene torch and "welding stresses" (i.e., thermally induced stresses equivalent to welding stresses) can thus be introduced without any metal fusion. Rapid local heating is necessary because large temperature gradients are required for the generation of residual "welding stresses." When a large torch is moved along the edge of a plate, the metal in the heated region expands. Since only a small volume of metal is hot at any instant, the expansion of the heated materials is restrained along the edge. Expansion and (at the higher temperatures) plastic flow can occur in either of the two unrestrained directions normal to the edge of the plate. Upsetting occurs when the temperature becomes high enough to induce compressive yielding. If the plate edge is heated progressively by moving the torch slowly from one end to the other, the material along the entire length will become thicker. After cooling, the upset edge will be too short to conform to the longer adjacent portions of the plate and tensile stresses will therefore be developed along the heated edge. Thus it can be seen that upsetting due to thermally induced compression stresses can cause residual tension stresses to develop. A study of residual welding-stress patterns reveals that upsetting is a major cause of residual welding stresses and that weld-metal shrinkage is a minor contributor. This will be further clarified by considering the behavior of a butt-welded joint.

A longitudinal butt weld joining two unrestrained large flat plates has a residual welding-stress pattern of the type shown in Fig. 1. The tension zone of the stress acting in the direction of the weld (i.e., the longitudinal stress) extends into the plate for a distance equal to several times the width of the weld. Beyond this region, the stress becomes compression, reaching a maximum value somewhere around $^1/_5$ of the yield strength. The maximum value of the longitudinal tensile stress is the yield strength of the metal, being around 40,000 psi for the weld zone of a mild-steel plate but sometimes reaching a value as high as 60,000 psi, particularly in weld metal made with higher-strength electrodes. It is of interest to note that had the residual stress been entirely due to weld-metal shrinkage, the residual stress pattern would have been entirely different. The tension-stress zone would have been confined to the weld metal; the stress in the base plate would have been entirely compression, with a high maximum at the junction of the weld metal.

Referring again to the stress in a butt-welded plate, the maximum tensile stress acting transverse to the direction of the weld is generally small in thin free plates, being only about 5000 psi in 1-in. thick 6-ft square plates.[1] With thicker plates, however, the transverse stresses may be much higher and may even reach the yield point of the steel. Unfortunately, very little data have been published on the effect of plate thickness on the magnitude of the residual stress. The author has made some tests on 6-ft square 1.5-in. thick plates of hot-rolled semikilled 0.20% carbon structural steel. The tensile properties of this steel and each of the two types of E6016 weld deposits made with a 350° F preheat are listed in Table 1. Standard 0.505-in. diam tensile bars were used for the tests.

The residual stresses found in these plates were as follows: longitudinal, 45,000 psi for the plate butt welded using stringer-bead technique and 37,000 psi for the plate butt welded using weave-bead technique; transverse, 12,500 psi for the stringer-bead plate and 11,000 for the weave-bead plate.

Hot-rolled medium-carbon structural steel plates 2.5 in. thick and approximately 4 ft square were tested by H. E. Kennedy.[2] He used two different welding techniques: (1) stringer beads with E6010 electrodes and no preheat, and (2) submerged-arc welding without preheat. For the first condition he found

Table 1—Tensile Properties of Mild-Steel Plate and E6016 Butt Welds

	Tensile strength, psi	*Yield strength, psi*	*Elongation, %*	*Reduction of area, %*
Plate				
As-welded	62,000	34,000	34	56
1100° F—2-hr stress relief	62,000	34,000	34	56
Low-temperature stress relief	62,000	34,000	34	56
Stringer-bead deposit				
As-welded	80,000	67,000	25	67
1100° F—2-hr stress relief	75,000	62,000	29	63
Low-temperature stress relief	77,000	64,000	25	58
Weave-bead deposit				
As-welded	86,000	77,000	24	62
1100° F—2 hr stress relief	76,000	67,000	27	68
Low-temperature stress relief	85,000	77,000	23	60

that the longitudinal stress was 58,000 psi and the transverse stress was 49,000 psi. For the second condition, the stresses were lower, being 28,000 psi for the longitudinal and 15,000 psi for the transverse.

It is apparent that residual welding stresses can vary markedly with plate thickness, plate size and with welding technique. Transverse stresses may approach the yield point in large thick plates joined by multipass welds. This is perhaps to be expected because in this case the last pass is placed after the plates have been joined into a rigid unified structure by the underlying weld passes. It is well known that local rapid heating of a spot on a large thick plate will produce yield-point stresses in all directions radiating from the spot. This condition is closely approached when the last pass of a stringer-bead weld joins two large plates.

The choice of welding electrodes and welding sequence can also have an influence on welding stresses. Jonassen, *et al*,[3] found a slight reduction in longitudinal stress (about 5000 psi in 1 in. thick mild-steel plates) when austenite electrodes were used. The results were substantially the same for both continuous weaving passes and for block-sequence welding. The same authors,[4] however, found that the longitudinal stresses in 1-in. thick butt-welded plates joined with E6010 electrodes could be lowered about 5000 psi by controlled block-welding-sequence procedures. The average transverse stresses were also somewhat lower when block welding was used.

The effect of peening on residual stress has also been investigated.[5] It was found that residual stresses in multipass butt welds made in 1-in. thick mild-steel plates with E6010 electrodes were unaffected by hot peening unless the last passes were peened. The last pass, if left unpeened, introduced yield-point longitudinal stresses. If, however, the peening were done after the welding has been completed and the weldment cooled to room temperature, the longitudinal stress could be reduced to about $\frac{1}{2}$ of the normal value.

DeGarmo[6] also found that preheating a $\frac{3}{4}$-in. x 2-ft x 3-ft plate of mild steel reduced the residual longitudinal stress to less than 15,000 psi. Kennedy,[7] however, working with $\frac{3}{4}$-in. thick, 12-in. wide plates found that preheating to 400° F had no significant effect on the longitudinal stress; yield-point stresses were found both with and without preheat. There is no clear-cut resolution of the effect of preheat on residual stresses. Very little data have been published and most of the pertinent information is incomplete. Theoretical considerations indicate that if preheat can be used to produce a temperature gradient that is nearly linear, then the residual stresses will be low. Perhaps the work of DeGarmo[6] approached this condition; in Kennedy's experiments, the plates were uniformly heated to 400° F, hence preheating may not have changed the maximum temperature gradient significantly. A more thorough investigation of the effect of preheating on residual stresses is in order.

Effects of Residual Stress

The vital question concerning residual welding stresses is—can such stresses cause or contribute to brittle failure? There is little doubt that certain kinds of welding stresses can and do cause fracture; about other kinds of stresses there is some uncertainty. There is one welded assembly that can be expected to crack regularly. It consists of a plate welded into a window-like opening in a large rigid structure. It is very difficult to avoid cracking in this kind of assembly because of the nature of the internal stress pattern developed by the welding. Such stresses are somewhat different from those generated in free butt-welded plates. They are called "reaction stresses" to distinguish them from the so-called "residual stresses" present in free butt-welded plates. These terms are commonly used to distinguish the two types of stresses but they are arbitrarily selected names and are not universally used. Reaction stresses are distinguished by the fact that they are uniform over relatively long distances, while residual stresses are highly localized and are associated with steep stress gradients. Reaction stresses can be relaxed by separating two parts of a structure by a single cut whereas residual stress cannot. For example, if a plate is inserted in an opening and welded at the top and bottom but not along the sides, a stress will be generated in the vertical direction which may be as high as the yield point. The stress will be uniform along the entire length of the panel because every cross section will have to carry the same load. This type of stress is a typical "reaction stress" and will load the panel like a tension member in a truss is loaded. A single cut (or a brittle fracture) will relax the stress throughout the entire length of the panel. A crack in a 3-ft long panel of this type which was subjected to yield-point stress could open about 0.036 in. by virtue of the relaxation of the stress. It is apparent, therefore, that a brittle fracture involving a total strain of a few hundredths of an inch could be caused by such a stress. There are many cases of fractures caused by reaction stresses and some of these will be discussed shortly. Before proceeding with this discussion, however, it is of interest to compare the behavior of a severed butt weld with that of a cut panel.

Examination of the behavior of a butt weld, in which the longitudinal stress is equal to the yield point, reveals that a cut across the weld at the mid-length of a 6-ft weldment will cause a strain relaxation of only 0.007 in. The very limited strain relaxation associated with the cutting or cracking of a butt weld is a consequence of the fact that residual stresses are relaxed for only a short distance back from the opening. Within 9 in. from the cut, the stress again reaches a maximum value. The reason for this is that the tension zone is directly attached to the compression zone in a butt-welded plate and hence the tension zone cannot relax freely when the weld is cut. Free and complete relaxation was possible in the panel only because the tension and compression zones were not connected except at the ends of the panel.

Brittle cleavage fractures could be produced across butt welds by residual welding stresses only if such fractures could form with a total plastic extension of only a few thousandths of an inch. Mild steel is rarely this brittle. It is therefore not surprising to find that fractures due to residual welding stress alone are almost impossible to produce in the laboratory. The corresponding incidence in service is equally rare. It should be noted, however, that some

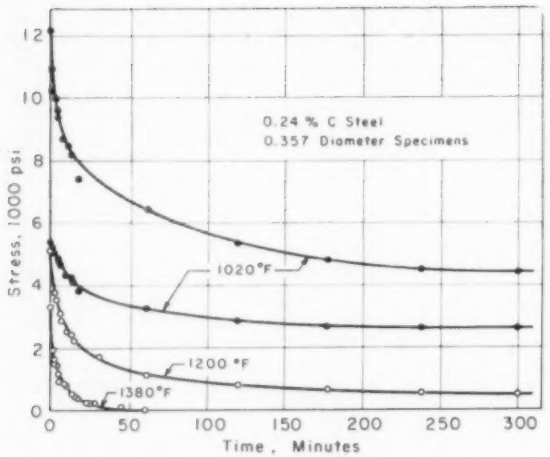

Fig. 2 Influence of initial stress and of temperature on relaxation of stress with time (Rominski and Taylor[15])

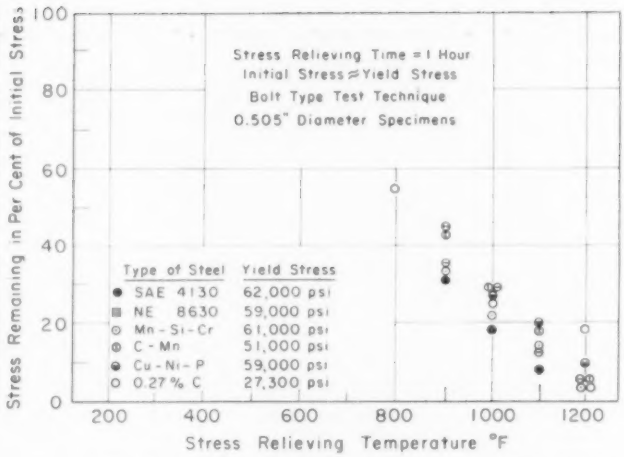
Stress Relieving Time = 1 Hour
Initial Stress ≈ Yield Stress
Bolt Type Test Technique
0.505" Diameter Specimens
Type of Steel Yield Stress
SAE 4130 62,000 psi
NE 8630 59,000 psi
Mn-Si-Cr 61,000 psi
C-Mn 51,000 psi
Cu-Ni-P 59,000 psi
0.27% C 27,300 psi
Stress Remaining in Per Cent of Initial Stress
Stress Relieving Temperature °F

Fig. 3 Influence of temperature on relaxation of stress in various carbon and low-alloy steels (Richards[16])

service failures have been caused by such stresses. Cracks evidently caused by residual welding stresses have occurred in unloaded penstocks and in large storage tanks. These cracks were short and grew at right angles to the weld, extending only a foot or so into the adjacent plates. If the structures in question had been subjected to normal service loads at the time the cracks formed, it is likely that the crack would have continued to propagate throughout the structure. The main danger from small transverse cracks in welds is that they form nuclei which may start large and potentially fatal fractures under service conditions.

Another question which has not been answered satisfactorily is concerned with the role of residual stresses in fatigue. Do residual stresses assist cyclic load stresses in producing a fatigue failure? There is fairly good agreement that residual compressive stresses can improve fatigue performance, but it has not been convincingly demonstrated that residual tensile stresses can be deleterious. Limited evidence indicates that ordinarily no harm is to be expected from residual welding stresses.

A slight amplification of the discussion about fatigue seems worthwhile. The fatigue strength of welded joints depends upon the design of the joint, the surface roughness, and the nature and extent of internal defects such as porosity, slag inclusions, poor penetration and shrinkage cracks. Rough surfaces can be smoothed by machining or grinding and external stress concentrations can be minimized by appropriate design. Internal defects may reduce the fatigue strength of weld metal to about half of the strength of similar weld metal free from such defects. When weld metal is properly fluxed and is free from porosity, cracks and other defects, the weld metal is as good in fatigue as the base metal.

It is well known from combined stress tests on unwelded specimens that a steady tension stress will lower the safe range of cyclic stress required to cause failure. However, the situation is somewhat different with residual welding stresses. Such stresses are not like those imposed by constant loads but are of the type produced by imposing a fixed strain on a piece of metal. When a cyclic stress is applied to a structure that has a high residual tensile stress, the material flows under the first few cycles of stress because the total combined stress cannot exceed the yield point of the material. Experiments have shown that residual welding stresses have a negligible effect on the fatigue strength of welded joints,[16] probably because the residual stresses were relieved by plastic flow during the first few cycles of stress.

Since all welds and adjacent areas contain a more or less complex pattern of internal stresses, distortion may be expected to occur when weldments are machined before stress relieving. The best insurance against dimensional instability during machining is an effective thermal stress relief. The degree of stability depends upon the maximum temperature attained during the stress-relieving treatment and upon the time held at that temperature. Shorter times at higher temperatures are much more effective in achieving stability during machining than are longer times at lower temperatures. As can be seen in Fig. 2, heating for 20 min at 1200° F is more effective in relieving stress than heating for 300 min at 1020° F.

Weldments consisting of assemblies of thick and thin sections must be cooled carefully from the stress-relieving temperature. Thin sections cool faster than thick ones and too-rapid cooling may establish temperature differences sufficiently large to cause a new pattern of residual stress to become established in the weldment. If this occurs, dimensional stability during machining cannot be assured even though the assembly had been stress relieved.

Service Failures

Shank[8] analyzed 64 structural failures in both riveted and welded structures, including tanks, bridges, pressure vessels, power shovels, gas transmission lines, a smoke stack and a penstock. Williams and Ellinger[9] examined many plates of steel taken from fractured welded steel ships and found an excellent correlation between service failures and low Charpy impact values in the plates where failures started. Since details concerning these failures are available elsewhere, they will not be presented here. However, some of the conclusions reached are pertinent and will be discussed.

The records of service failures, while not entirely conclusive, indicate that residual stresses by themselves are not a primary cause of service failure but, at low temperatures, they may combine with other stresses to produce a brittle fracture of the structure at less than the anticipated strength of the structure.

Procedures for Stress Relieving

Residual welding stresses may be relieved by either of two basic methods—one is thermal, the other is mechanical. Thermal stress relieving involves heating the weldment to a preselected temperature (e.g., 1150° F), holding it at this temperature for a few hours, and cooling rather slowly thereafter. Mild steel cannot sustain high stresses at the stress-relieving temperature and hence the stresses relax by a creep or plastic-flow process.

The simple theory of thermal stress relieving is that the residual stresses are reduced by the thermal treatment to the value of the yield strength of the material at the temperature of the

treatment. This is a good first approximation but is only part of the story. Since steel creeps slowly under stress at the temperatures used for stress relieving, the stress gradually relaxes and may drop substantially below the short time yield strength at the heat-treating temperature. The yield strength for mild steel is given as a function of temperature in Table 2. In Fig. 2 the change in residual stress with time is shown for several temperatures. For example, at 1020° F an initial stress of 12,000 psi (only about $^1/_2$ of the short-time yield strength) dropped to less than half that value in about 2 hr. Even the much lower initial stress of 5500 psi decreased to half the initial value in a 2-hr period. Thus, it can be seen that time as well as temperature is important and that stress relaxation by creep may contribute substantially to the stress-relieving process.

The temperature and time required to reduce the residual welding stress to an unimportantly low value varies with the type of steel. While 1 hr for each inch of thickness at 1100–1200° F is recommended practice for plain-carbon steel, this treatment may not be satisfactory for alloy steels. For example, a 7% chromium, 0.5% molybdenum steel requires a postheat treatment of 1350–1400° F. This is in part due to the fact that most alloy steels are more creep resistant than carbon steels and so higher temperatures are required to relieve the residual stresses.

A further complication arises from complex metallurgical changes that occur in some alloy steels in the stress-relieving temperature range. For example, the alloy-steel weld metal deposited by some E100xx and E120xx class electrodes undergoes an embrittling metallurgical change when postheated to 1100° F.[10, 11] In one case, an E12015 weld-metal deposit had a ductility transition temperature of −60° F in the as-welded condition but this transition was raised to +130° F by a stress-relief heat treatment. The rise in transition temperature in this case was, very likely, caused by the precipitation of vanadium or molybdenum carbides. It should be kept in mind that when alloy steels are used, complications are possible and the welding and heat-treating procedures should be carefully selected. A lengthy table giving recommended procedures for the welding of all of the important commercial steels has been prepared by Stout and Doty;[12] the reader is referred to the original table for details.

Thermal treatment is a very effective means for removing welding stresses and is in common use. One of the biggest assets of thermal stress relieving, however, is the beneficial tempering of the weld metal and heat-affected zone of the base plate. When martensite is present, the microstructural change can be detected readily. The normal structure in the heat-affected zone in mild steel is bainite and the changes produced in this structure are very difficult to detect by microscopic examination. In mild steel, the ductility of the metal in these regions may be substantially lower than that of the base plate. The tempering which occurs during stress relieving produces a favorable alteration in microstructure and so the metal becomes tougher and more ductile. A large part of the improvement produced by thermal stress relieving seems to be due to the metallurgical changes and not to the relaxation of welding stresses. This is perhaps best illustrated by the behavior of Charpy specimens cut from weldments. Such specimens are too small to retain welding stresses but often show marked improvement in toughness when reheated to a stress-relieving temperature. The eccentric notch-bar test results shown in Fig. 4 illustrate this point.

Table 2—Mechanical Properties of Mild Steel at Elevated Temperatures[22]

Temperature, ° F	*Tensile strength, psi*	*Yield point, psi*	*Elongation, % in 2 in.*	*Reduction of area, %*
70	60,000	39,000	48	66
300	67,000	36,500	28	60
500	67,500	32,000	29	62
700	59,500	26,000	36	68
900	41,000	19,500	45	76
1100	21,000	12,500	57	86
1300	10,500	6,000	69	96

Mechanical stress relieving, the second commercial process used for relieving welding stresses, is accomplished by stretching plastically the regions in a weldment that are under tension. The amount of plastic extension must equal the elastic strain due to the residual stress if stress relief is to be effected. There are several procedures employed for mechanical stress relieving. Circumferential seams in a pressure vessel can be stretched by applying internal pressure to the vessel. A longitudinal butt weld joining two plates can be stretched in a tensile machine until the weld zone is elongated enough to eliminate the elastic strain in the tension zone. A structure, such as a ship, which can neither be loaded hydraulically nor stretched in a machine, can be stress relieved by a recently developed process called "low-temperature stress relieving."[13] This process involves the heating of two bands adjacent to and parallel with the weld to a controlled low temperature, i.e., about 350° F, while keeping the weld zone cool. The heating is done with two wide acetylene torches adjusted so that they heat 6-in. wide bands running parallel to the weld and from 3 to 9 in. out from each side of the weld. The torches are attached to a carriage that moves them along at a uniform rate. Water is sprayed on the weld to keep it cool and on the heated portion of the plates after the torch has passed to effect quick cooling. The heated zones expand, stretching the weld zone. The weld zone, being at its yield stress, flows plastically as it stretches. By controlling the amount of plastic straining (i.e, by controlling the maximum temperature of the heated zones), the longitudinal weld stress can be reduced to a low value or, under certain conditions, it may even be reversed.

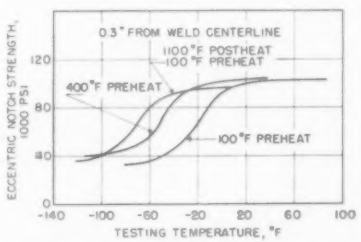

Fig. 4 Effect of preheating and post-heating on the notch ductility of the most-brittle zone of welds in mild-steel plates (Klingler and Ebert[20])

Although it is difficult to prove that low-temperature stress relieving is beneficial in minimizing brittle fracture, there are some indications that this is so. The process is gaining in popularity and is currently used on ships, tanks, penstocks and other large structures. It is relatively inexpensive and hence provides cheap "accident insurance." There are certain applications where low-temperature stress relieving has proven to be a boon, namely those where stress corrosion of welds is a problem. Under certain conditions stress-corrosion cracking can occur in welded mild-steel structures. Such cracking may be either intergranular or transgranular, depending upon the nature of the corrosive environment. A well known example of stress-corrosion cracking is the caustic embrittlement of steel in steam boilers. This cracking is caused by the presence of sodium hydroxide in the water—hence the name caustic embrittlement. Some ni-

trate solutions also cause rapid stress-corrosion cracking. Concentrated calcium nitrate and concentrated ammonium nitrate, as well as other nitrates, are known to cause such cracking. Cracking has been observed in tanks holding certain gases under pressure. This cracking was apparently caused by moisture and traces of hydrogen cyanide or to moisture and traces of hydrogen sulfide.

Stainless steels are also susceptible to stress-corrosion cracking. The stresses required to cause cracking in stainless steels are low, 20,000 psi sometimes being sufficient. Most cases of cracking occurred when chloride ions were present and particularly in acid solutions. Ferritic stainless steels are less susceptible to stress-corrosion cracking than are the austenitic steels. The incidence of cracks caused by stress-corrosion may be reduced to a very low value by either thermal stress relieving or by mechanical stress relieving.[14] Thermal stress relieving is best, but low-temperature stress relieving can be used on large simple structures having no complicated attachments or connections. Mechanical stress relieving is ineffective where there are attachments, right angle connections and other discontinuities that normally function as stress raisers.

Peening is also employed as a mechanical means for relieving stress. It is generally done with a pneumatic hammer equipped with a smooth faced tool. Neither the root pass nor the cover pass is ordinarily peened. As was mentioned earlier, peening has little effect upon the residual welding-stress pattern for 1 in.-thick plate unless the final pass is peened.[5]

The API-ASME Code permits peening to be substituted for thermal stress relieving in the case of large field-assembled vessels. However, in view of the evidence showing that stress relief is not accomplished unless the final passes are peened, and this is usually not done, peening is considered by many to be a poor substitute for thermal stress relief.

Peening is effective in controlling distortion and minimizing weld cracking. Consequently, it is used fairly extensively in commercial practice.

Factors Influencing Stress Relief

A number of factors influence the relief of residual stress. Among these are initial stress level, time, temperature, composition of the steel and microstructure. The effect of initial stress level (see two curves for 1020° F in Fig. 2), temperature, and of time are shown in Fig. 2 as determined by Rominski and Taylor.[15] The rate of stress relief is initially high but decreases rapidly with time. The stress-time curves are typical stress-relaxation curves. The decreasing rate is due to the fact that the stress is decreasing and also to the fact that creep rate decreases with time even at a constant stress. D. G. Richards[16] reported the data compiled by Jelm and Herres[17] shown in Fig. 3. Points are shown for six steels. The graph represents the percent of initial stress remaining after a 1-hr period at the indicated temperature. The influence of composition and microstructure have not been put on a quantitative basis, but it is evident from known creep data that both factors can have a substantial influence. It is safe to say, however, that a temperature of 1100 to 1200° F will remove more than 80% of the initial stress for carbon and low-alloy steels. For special creep-resisting steels, higher temperatures are required. Stress relieving at lower temperatures, for example at 700° F, may be advantageous when postheating to higher temperatures is impractical. Even at this temperature $^1/_2$ or more of the residual stress may be removed.

Section size is also important because it determines the length of soaking time required to insure that all parts of a structure are at the same temperature. It is common practice to hold steel parts at the stress-relieving temperature for one hour for each inch of thickness. Thus a plate 1 in. thick would be held at 1100-1200° F for 1 hr but, if it were welded into an assembly containing another piece 4-in. thick, the assembly would be held at temperature for 4 hr. There is no known scientific basis for this practice, but it has been found to be a very satisfactory rule to follow. In addition to holding one hour per inch of thickness, the code requires that the rate of heating should not exceed 400° F per hour divided by the thickness. The heating rate must be controlled for complex structures because fast heating would induce large temperature differences and hence tend to cause warpage and distortion.

Preheating may, under certain circumstances, reduce distortion by reducing local temperature differences. A reduction in distortion is often associated with a reduction in reaction stresses; judicious preheating may thus be an aid in reducing one kind of welding stress.

The effect of preheating on residual stress has not been thoroughly explored. Kennedy[7] reported the results of residual-stress measurements on 12-in. wide $^3/_4$-in. thick steel plates. He found that preheating to 400° F had no significant effect on the pattern of residual stress and that the maximum stress was equal to the yield strength of the metal. DeGarmo[6] reported the results of residual stress measurements on a 30- x 36- x $^3/_4$-in. thick steel plate that had been preheated to 400° F. He found that the maximum stress was less than half the yield strength of the steel. Residual stresses are introduced because of large temperature gradients and hence the effect of preheating on residual stress cannot be simply appraised; the effect of the preheating on the temperature gradient is undoubtedly much more important than is the maximum local temperature attained by preheating. Data available to date are so meager that it is impossible to arrive at a clear picture of the effect of preheat on residual stress.

There is a further complication with pearlitic steels of all compositions. Some regions of the heat-affected zone will not be heated high enough above the transformation temperature to permit the carbon in the pearlitic areas to diffuse into the adjacent metal. Such areas will transform to austenite of eutectoid composition, even in medium- and low-carbon steels, and will form regions of high-carbon martensite if cooled too quickly.

The possibility of residual stresses being relieved by working stresses has been studied in considerable detail on ships.[18] Planned hogging and sagging tests showed that some relief took place in areas where initial stresses were very high but the amount of stress relaxed was considerably less than the value of the applied stress. Checks were also made on ships that had been in service for various periods of time but no significant relaxation of stress could be detected.

Effect on Mechanical Properties

The microstructure of a weld deposit is controlled by two factors, (1) the chemical composition and (2) the thermal history. With a given composition, the microstructure (and hence the mechanical properties) may be altered over a wide range by variations in cooling rate or by a post-welding heat treatment. In as-welded mild-steel plates, the most ductile weld zones result when preheating is used; preheating retards cooling, a condition favoring increased toughness. Thermal stress relieving and normalizing are even more beneficial insofar as improving notch toughness is so concerned.

Thermal stress relieving has long been known to improve the mechanical properties of carbon-steel weldments. This treatment produces several beneficial effects. Stresses are relieved and thus the danger of welding stresses contributing to a brittle fracture are eliminated, distortion during subsequent machining is avoided, and cracking due to stress corrosion is minimized.

Further improvements are also frequently realized because of the metallurgical changes that occur during the thermal stress-relieving treatment. Improvement in bend-test ductility of

welded mild steel produced by postheating has been demonstrated in many investigations.[12] With E6010 electrodes, part of this improvement is undoubtedly due to the escape of hydrogen from the weld zone.[12, 19] Welds made with such electrodes show a progressive improvement in notch ductility when postheated or even when aged for many days at room temperature. Similar welds made with low-hydrogen electrodes, however, do not change in properties when aged at ambient temperature. Furthermore, since such deposits are normally "notch tough," i.e., have low 15-ft-lb V-notch Charpy transition temperatures, their notched-bar properties are affected much less by postheating than are E6010 weld deposits.

The heat-affected zone in a single-pass weld will have a maximum hardness that is determined solely by the composition of the base plate and by the thermal history of this zone during welding. The heat-affected zone adjacent to the top pass of a multipass weld will be like that of a single pass weld when the final pass is placed on a cold weldment. The maximum Knoop microhardness values found by the author in the heat-affected zone of single-pass welds are listed in Table 3 for various electrodes and for various preheat and postheat treatments. The current, voltage and rate of travel were maintained constant for all deposits. It can be seen that the hardness of the heat-affected zone is independent of the type of electrode used but is markedly altered by preheat or postheat treatments. Preheating is very influential in reducing the hardness of the heat-affected zone; postheating at 1100° F is markedly effective in lowering the maximum hardness. Normalizing, of course, completely alters the microstructure, producing pearlite and ferrite in the heat-affected zone in mild steels.

In multipass welding, the conditions are usually much different from those encountered with single-pass welds. The overlying passes reheat and temper those passes previously deposited. Furthermore, the final pass is frequently deposited while the weldment is still hot from the earlier welding. In this case, the last pass is deposited under "preheat" conditions. Occasionally, however, the final pass is deposited on a cold weldment. Also, repair welds are frequently made without preheat. In these cases, E6010 deposits tend to be "notch brittle" and postheating to the stress-relieving temperature can be very beneficial in improving notch toughness.

Certain defects may be introduced by improper welding procedures. Examples of such defects are porosity, inclusions, excessive increase in certain embrittling alloying elements such as silicon, hot or cold cracks, underbead cracks, poor penetration and undercutting. Such defects obviously cannot be corrected by heat treatment. The improvement in properties produced by postheating is due to a diminution of residual stress and to favorable changes in the microstructure of the weld metal and heat-affected zone.

Postheating above the transformation temperature, e.g., normalizing, refines the microstructure and reduces the welding stresses to zero. (Nonuniform cooling can, however, reintroduce residual stresses.) Stress-relief treatments carried out at 1100 to 1200° F reduce the residual stresses to unimportant values and temper the weld metal. Heating to lower temperatures reduces residual stresses but much less effectively than does the higher-temperature heating. Reference to Fig. 3 shows how rapidly the remaining stress drops with increasing temperature. However, it is known that even low-temperature postheating will liberate appreciable quantities of absorbed hydrogen and this apparently has a beneficial effect on notch ductility.

A great deal of experimental work has been done to evaluate the effects of preheating and postheating. The general changes produced are typified by the results of Klingler and Ebert[20] shown in Fig. 4. They compared the transition temperatures of a $^3/_4$-in. thick welded plate of mild steel with various heat treatments. Eccentric notch-tension specimens were used for evaluating the behavior of the hand-welded double-V joints made with a controlled sequence of six passes using $^5/_{16}$-in. E6010 electrodes on reverse polarity. Preheating to 400° F was definitely beneficial in lowering the transition temperature of the most brittle zone in the weldment (the heat-affected zone of the base plate). Postheating to 1100° F was even better than preheating and lowered the transition temperature still further. These results are typical of many and illustrate the beneficial effect that can be produced with *medium-carbon structural steel* by either preheating to about 400° F or by postheating to a "stress relief" temperature. A preheat of 400° F is rather uncommon for plain-carbon steel; preheating in the 200-300° F range is more frequently employed. The magnitude of the improvement provided by preheating is substantially proportional to the preheat temperature. Preheating mild steels above 400° F produces little additional improvement and may actually result in less improvement than that associated with a lower preheat temperature. High preheat temperatures retard cooling so much that coarser structures (and consequently poorer properties) result. The optimum preheat temperature will vary somewhat even for a given steel, being dependent upon the welding conditions and the plate thickness. For $^3/_4$-in. thick mild-steel plates, it is in the neighborhood of 300 to 400° F. Low-alloy steels require higher preheat temperatures, sometimes up to 700° F, for optimum properties. Such high preheat temperatures, however, may introduce other complications, such as the danger of austenite retention, as was pointed out in an earlier section.

Table 3—Maximum Knoop Microhardness Values for Heat-Affected Zone in Hot-Rolled AISI 1020 Steel*

Welding condition†	*Maximum hardness*
Type 310 stainless electrode, 70° F plate temperature	450
Type E10016 electrode, 70° F plate temperature	450
Type E6010 electrode, 70° F plate temperature	450
Type E6010 electrode, 200° F plate temperature	275
Type E6010 electrode, 300° F plate temperature	250
Type E6010 electrode, 400° F plate temperature	225
Type E6010 electrode, 70° F plate temperature, 1100° F postheat	250
Type E6010 electrode, 70° F plate temperature, 1050° F postheat, air cooled	150

* Knoop hardness of base plate = 150.
† All welds single pass.

A phenomenon known as temper brittleness results when certain low-alloy steels are held within, or cooled slowly through, a certain temperature range. Temper-brittle steels become much more notch brittle (with transition temperatures raised several hundred degrees) when slowly cooled through this range. The normal stress-relieving temperature of 1100 to 1200° F is above the range causing temper embrittlement, but slow cooling after stress relieving may ruin a steel insofar as notch toughness (i.e., resistance to brittle fracture) is concerned. The temperature at which steels are most susceptible to temper embrittlement is in the neighborhood of 900° F (this statement, of course, does not apply to plain-carbon steels). Slow cooling while above 1100° F or below about 500° F has little effect. If a steel has been embrittled by slow cooling, its toughness may be restored by reheating to above 1100° F and cooling quickly. Not all low-alloy steels are susceptible to temper embrittlement, but alloy steels (or alloy deposits of weld metal on mild

steels) should be checked for embrittlement whenever thermal stress relief is employed. Chromium steels, chromium-nickel steels, and steels with manganese on the high side are particularly susceptible to temper embrittlement. Plain-carbon and nickel-alloy steels rarely exhibit such embrittlement. Additions of molybdenum decrease the tendency of a steel to temper embrittle. Stout and Doty[12] have listed recommended conditions for preheating and postheating a variety of steels.

Although the available evidence from laboratory tests and service records clearly indicates that postheating to 1100-1200° F is beneficial, there are indications that postheating may sometimes raise the transition temperature of the weldment. Stout and McGeady[21] measured the change in transition temperature produced by heating mild-steel plate to various subcritical temperatures. They found that the ductility transition temperature (in this instance selected on the temperature to obtain 1% lateral contraction at fracture measured at bottom of sharp notch) rose about 50° F when the base plate was heated to 1200° F. The reason for the rise in ductility transition temperature is not known but it could be due to the increased carbon solubility in alpha iron in the 1100-1300° F temperature range.

Pellini and Eschbacher[22] also found that some alloy steels are deleteriously affected by postheating in the 1100-1200° F range. They found that postheating to 1150° F raised the transition temperature of some alloy-steel weld specimens as much as 100° F. It must not be presumed, therefore, that postheating is universally beneficial. Experience and judgment should be used to modify standardized procedures in questionable cases.

Austenitic chromium-nickel weldments behave differently from those made with carbon or low-alloy steel. Brittle behavior is no problem in austenitic steels; they remain tough and ductile even at the lowest temperatures. With such steels, loss of corrosion resistance is a major problem. Corrosion is generally localized in the heat-affected zone where carbides tend to precipitate during welding. When carbide precipitation has occurred, it can be eliminated by reheating the weldment to 1900 to 2000° F and cooling rapidly. A heat treatment of this type is very drastic and cannot be employed for complex structures; furthermore, warpage due to the fast cooling may be severe even with simple structures. The presence of sufficient columbium or titanium (e.g., ten times the carbon content) in the steel will minimize the harmful effects of carbide precipitation, hence the use of such stabilized steels is recommended when welding is to be employed. Carbide precipitation problems can also be avoided by use of extra-low-carbon grades of stainless steel.

When stainless steels are used for certain applications, stress corrosion becomes a problem. Such steels should preferably be given a solution heat treatment in the 1900-2000° F range and cooled quickly. If solution heat treatment is not possible, stress relieving in a temperature range of 1600–1650° F is recommended. Lower-temperature treatments, e.g., 1350 to 1400° F, are sometimes employed but the lower-temperature treatment is inferior. A temperature of 1375° F eliminated only about 50% of the stress while 1650° F relieves about 90%. Care must be taken with unstabilized steels to check stress-relieving procedure for its effect on corrosion resistance because deleterious carbide precipitation may occur in the temperature range employed for stress relieving. This may seriously impair the utility of the steel. However, holding for four or more hours at 1650° F will generally permit diffusion of sufficient chromium into the depleted regions around the precipitated carbides to markedly improve the corrosion resistance.

Stainless-clad steels may be stress relieved at 1100 to 1150° F to relieve the stresses in the base material. Even this treatment, however, may cause some carbide precipitation to occur. Since the amount of precipitation will vary for different steels, it is sometimes worthwhile to check the effect of the stress-relieving treatment on the properties of the steel prior to the final treatment.

Summary and Conclusions

Conflicting evidence concerning the effect of welding stresses has led to a great deal of confusion. Reaction stresses are known to be dangerous and in general should be relaxed by an appropriate stress-relieving process prior to service. Residual stresses rarely contribute to brittle fracture but may, under certain circumstances, be very deleterious. Although failure of structures in service are not numerous when compared with the total number of structures that are welded, the failures that have occurred have been of sufficient importance to warrant serious consideration of welding stresses or whatever else may be the cause of such failures.

Service failures rarely occur solely because of welding stresses; defective welding combined with other factors has been largely responsible for recent service failures. With few exceptions, cleavage cracks in welded ships have originated at weld defects. Rarely have cracks been observed to start in sound welds in any type of engineering structure. Except where severe weld defects are present, postheating to 1100 to 1200° F will minimize brittle service failures in mild steel because of the reduction in residual stresses and because of the marked improvement in notch toughness brought about by this treatment. The use of low-hydrogen electrodes may be advantageous when neither postheating nor preheating can be employed; it is essential for alloy steels containing more than about 0.30% carbon.

With certain alloy steels, care must be exercised in selecting preheating and postheating procedures. High preheat temperatures may encourage the retention of austenite which subsequently transforms to martensite. Postheating to 1100-1200° F may actually induce brittleness in certain steels.

Mechanical stress relieving and the low-temperature stress-relieving process can be very effective in relaxing residual stresses. It is becoming increasingly popular for use on simple large structures that cannot be thermally stress relieved. When such structures are subjected to conditions that foster stress-corrosion cracking, mechanical stress relieving may be advantageous.

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ALUMINUM AND ALUMINUM ALLOYS FOR PRESSURE VESSELS

Discussion of paper originally published as Welding Research Council Bulletin No. 28 and abstracted in Welding Research Supplement, June 1956

BY MARSHALL HOLT

I should like to amplify the discussion of two points in my article "Aluminum and Aluminum Alloys for Pressure Vessels," Bulletin No. 28 of the Welding Research Council Series, a condensed version of which was published in the Welding Research Supplement June 1956, pp. 308-s to 312-s.

The first point relates to the determination of allowable stress values. The stress values for the aluminum alloys in Section VIII of the ASME Code for Boilers and Pressure Vessels were established in accordance with Par. UA-602 of Section VIII. The criteria in this paragraph provide that the stress value must not exceed (1) one-fourth of the tensile strength and (2) two-thirds of the yield strength as determined by test on specimens which had been exposed to the testing temperature for as long as 10,000 hr. Until recently, it was believed that the stress values determined by these criteria would be no greater than those determined by the criteria in Par. UA-601 which are as follows: (1) one-fourth of the tensile strength, (2) two-thirds of the yield strength, (3) the stress producing a secondary creep rate of 0.1% in 10,000 hr and (4) four-fifths of the stress producing rupture in 100,000 hr. As stated in Par. UA-601, the tensile and yield strengths are obtained from standard short-time tests; the creep and stress-rupture strengths are determined by extrapolation of the trends of the data. Both paragraphs UA-601 and UA-602 provide that the tensile strengths and yield strengths be adjusted to represent material which just passes the specification requirements.

New data on aluminum alloys approved for Code vessels indicate that, for certain alloys, criteria 3 and 4 of Par. UA-601 do lead to lower allowable stress values than do the criteria of Par. UA-602 for the temperature of 400° F. In recognition of this situation, Aluminum Co. of America recommended, and the ASME Boiler and Pressure Vessel Code Committee has taken action to adopt,* the following three-point program:

(1) Change the fourth criterion in Par. UA-601 from "four-fifths of the stress to produce rupture in 100,000 hours" to "the stress to produce rupture in 100,000 hours" (in order to make the criteria in Par. UA-601 identical with those in Par. UA-500 for ferrous materials to be used in Section VIII vessels).

(2) Delete Par. UA-602.

(3) Change the stress values in Table UNF-23 as indicated.

The criteria for determining allowable stress values are being given further study by the Special Committee to Review the Code Stress Basis, appointed by the ASME Boiler and Pressure Vessel Committee.

The second point that I should like to discuss relates to the determination of the hydrostatic test pressure in the ASME Code. Some readers of the Bulletin thought I disagreed with the Code practice of setting the test pressure at 1.5 times the design pressure. This was not my intention, since, even if the stresses under the test pressure were equal to the yield strength, the resulting permanent distortions would be of such small magnitude that they would not be objectionable from the standpoints of either appearance or safety. As stated in the Bulletin, the yield strength of the aluminum alloys is the stress associated with a permanent set of only 0.002 in. per in. and does not represent a significant structural action as does the yield point of mild steel.

* Published in *Mechanical Engineering*, April 1957, pp. 394-395. If no objections are received by ASME, these provisions will become effective as part of the Code.

Table UNF-23

Alloy				For metal temperature not exceeding 400° F	
	Commercial				
ASTM	old	new	Temper	From	To
990A	2S	1100	H12	2 100	1 700
			H14	2 200	1 700
MG11A	4S	3004	H32	4 300	3 500
			H34	4 700	3 500
Clad MG11A	Alclad 4S	Clad 3004	H32	4 100	3 400
			H34	4 600	3 400
G1A	50S	5050	0	2 800	2 100
			H112	2 800	2 100
			H32	2 800	2 100
			H34	2 800	2 100
GR20A	52S	5052	0 & H112	3 900	3 500
			H32	4 800	3 500
			H34	5 300	3 500

Note: No changes are suggested for alloys 996A, M1A, Clad M1A, GS10A, GS11A, Clad GS11A, GS11B, GS11C, CG42A, and CS41A or for the alloys listed in the table above at any temperature other than 400° F.

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THE WELDING OF TYPE 347 STEELS

Statistical analysis of effects of various elements on the crack sensitivity of fully austenitic Type 347 welds

BY ARTHUR HOERL AND THOMAS J. MOORE

ABSTRACT. Commercial fabricators of Type 347 stainless steel employ welding electrodes which will deposit partially ferritic weld metal. In this way the cracking problem of as-deposited weld metal is circumvented. Unfortunately, ferrite is sometimes found objectionable, especially in high temperature applications where embrittlement can occur and hence the desire to develop a crack-resistant fully austenitic weld metal.

The program reported here is only concerned with the cracking tendency of fully austenitic Type 347 weld metal. None of the weld metal compositions investigated contained any ferrite whatsoever.

By using a sensitive segmented circular-groove cracking test, and a statistical interpretation of the effect of varying specific elements, a closer approximation to the ideal composition of a crack-resistant fully austenitic Type 347 weld metal has been realized.

Carbon and manganese are shown to be the most potent elements in reducing cracking, and phosphorus and sulfur are the strongest and most definite crack promoters. Silicon appears to have less effect in promoting cracking than was thought heretofore. Chromium, nickel, columbium + tantalum, and nitrogen were not intentionally varied; thus the indicated cracking effects of these elements are largely speculative.

The composition of the base material as well as the electrode was considered in calculating the weld bead chemistry which was used in the statistical study.

All electrodes used in these tests employed a lime-type covering. With the use of other types of coated electrodes or other welding processes the exact relationship developed here may not be applicable.

Introduction

Unsoundness in Type 347 weld deposits as revealed by cracks or fissures is a major problem unless proper precautions are taken to insure a duplex microstructure. For this reason commercial electrode manufacturers balance the chemistry of the weld metal to insure a ferrite content of 4 to 8%. In service applications where the fear of sigma-phase embrittlement would be a problem, it is desirable to have the ferrite as low as possible. A 1 to 4% ferrite weld deposit is often chosen for such applications even though the chance of unsound weld metal due to dilution with the base material may be increased.

In earlier investigations of alloys which are single-phase austenite at room temperature, it has been observed that the fissure tendency of tensile bars appears to be a function of the composition. In an investigation[1] of the 25 Cr–20Ni weld metals, carbon, silicon and phosphorus were shown to influence the fissuring tendency and consequently the elongation values of the tensile test. A similar study[2] of 15Cr–35Ni welds showed the desirability of high carbon and low silicon. These observations have been confirmed by tests conducted by Linnert and Bloom,[3] Carpenter and Jessen,[4] and Benz and Caughey.[5] Kauhausen's work[6] indicates that high manganese content is effective in overcoming cracks because it combines with sulfur, which he believes to be harmful. In nickel-base weld metals of the Inconel types, Kihlgren and Lacy[7] also found silicon to be harmful and have proposed that cracking can be controlled by maintaining a minimum value of the columbium-to-silicon ratio.

In the presentation to follow, an attempt is made to develop a single formula which can be used to predict and thus ultimately lead to control or elimination of cracking in fully austenitic Type 347 weld deposits. No ferrite was present in any of the weld metal compositions studied, thus ruling out the effect of this variable

Test Procedure

All electrodes used in this investigation were prepared using a standard lime-type coating containing no titania. The plate materials were heated to 1950° F for ½ hr and water quenched to avoid a possible variable due to plate heat treatment.

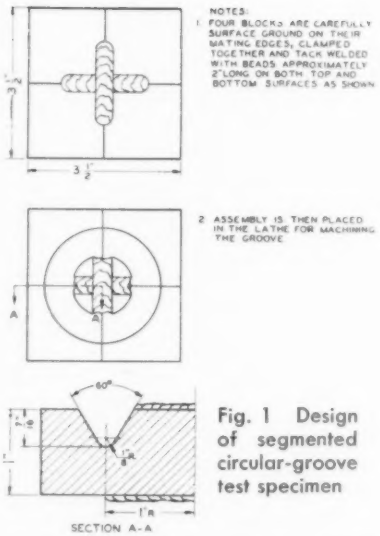
NOTES:
1. FOUR BLOCKS ARE CAREFULLY SURFACE GROUND ON THEIR MATING EDGES, CLAMPED TOGETHER AND TACK WELDED WITH BEADS APPROXIMATELY 2" LONG ON BOTH TOP AND BOTTOM SURFACES AS SHOWN
2. ASSEMBLY IS THEN PLACED IN THE LATHE FOR MACHINING THE GROOVE
60°
SECTION A-A

Fig. 1 Design of segmented circular-groove test specimen

In conducting the segmented circular-groove cracking test, welding is done in the flat position beginning at "11 o'clock." The welding proceeds clockwise for 240 deg ending at the "7 o'clock" position where the arc is broken rapidly. A $^{5}/_{32}$-in. electrode is used at 128 to 130 amp, 24 v and a forward speed of 6 ipm. After the specimen has cooled to below 200° F, the remaining 120 deg is welded with a new electrode. The test specimen is examined for weld-metal cracks 24 hr later using a binocular microscope.

For this type of test specimen (Fig. 1), cracking initiates at the mating surfaces of the segments. In severe cases the cracking extends along the centerline of the weld metal. The percentage of cracking is calculated using the ratio of the lengths of all the cracks to the circumference of a 2-in. diam circle; the crater length is not included in this computation.

Crater cracks, though observed and

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Presented on behalf of the Advisory Committee for Welding of Stainless Steels, High Alloys Committee, Welding Research Council. Chairman: V. N. Krivobok; Members: W. O. Binder, F. W. Davis, W. B. DeLong, R. B. Gunia, M. A. Scheil, R. D. Thomas, Jr., and T. J. Moore, Secretary.

Work performed under Contract No. AT(30-1)-1233.

Table 1—Chemical Analyses of Base Plates

Plate no.	C	Mn	Si	S	P	Cr	Ni	Cb + Ta	N	Mo	Cu	O
	%											
4	0.059	1.31	0.46	0.020	0.022	18.08	10.94	0.77	0.022	0.14	0.15	0.021
8	0.080	1.57	0.61	0.011	0.028	17.46	10.98	0.82	0.042	0.15	0.26	0.008
12	0.058	1.28	0.48	0.009	0.016	18.70	10.82	0.65	0.021	0.09	0.09	0.015
13	0.048	1.78	0.65	0.006	0.018	18.41	10.57	1.05	0.012	0.12	0.21	0.004
14	0.053	1.49	0.60	0.006	0.017	18.50	9.45	0.65	0.026	0.22	0.32	0.007
15	0.045	1.68	0.77	0.015	0.016	18.33	9.96	0.98	0.020	0.11	0.11	0.015
17	0.075	1.31	0.42	0.016	0.022	17.55	10.53	0.77	0.014	0.07	0.11	0.024
19	0.059	1.73	0.56	0.008	0.025	19.50	11.11	0.88	0.031	0.00	0.19	0.022
20	0.078	1.42	0.29	0.010	0.023	17.85	10.06	0.67	0.028	0.26	0.25	0.013
21	0.096	1.55	0.81	0.008	0.023	17.31	10.75	0.89	0.011	0.28	0.47	0.008

measured, are ignored because experience has shown that crater cracking is largely a function of the manner in which the arc is broken. A photograph of a typical segmented circular-groove test specimen is shown in Fig. 2

Two welders, "X" and "Z," were employed in preparing the test specimens. Thirty-one modified Type 347 weld metal compositions and ten base plates complying with the Type 347 specification were used.

The elements that were varied intentionally were carbon, manganese, silicon, sulfur and phosphorus by additions to the covering on the appropriate core wire.

Test Results

Chemical Analysis of Weld Beads

The chemical analyses of the weld beads which were deposited in the segmented circular-groove specimens were computed from the electrode compositions by taking into account the base metal dilution. This method requires the sectioning and careful examination of a sufficient number of samples (approximately 12) to obtain a reasonable estimate of the proportion of the base metal dilution (see Fig. 3).

In Table 1 are listed the chemical analyses of the base materials and in Table 2 those of the undiluted weld metal. The calculated weld bead chemistry is given in Table 3 for welder "X" and in Table 4 for welder "Z." In the latter table the core wire analyses are also presented. The efficiency with which the various elements are transferred across the arc did not have to be considered here since the electrode analyses which were used in the calculations were undiluted weld metal analyses.

It should be noted that the welders did not have the same dilution factors, i.e., welder "X" averaged 32% dilution and welder "Z" averaged 24%. This difference was taken into account when calculating weld bead chemistry, as may be noted in the illustrative calculations at the top of Tables 3 and 4.

An attempt was made to obtain a check of the calculated percentages of phosphorus and sulfur for the welder "Z" tests. This check was made by very carefully obtaining chips from the weld bead and using microanalysis techniques to determine the chemistry.

A following comparison of nine calculated versus microanalyzed values for phosphorus for welder "Z" (test nos. 4 to 12) revealed that seven values agreed within 0.006% phosphorus; the other two values differed by 0.011 and 0.013%, respectively.

Test no.	Calculated	By microanalysis
	%	
4	0.025	0.014
5	0.033	0.031
6	0.049	0.048
7	0.030	0.017
8	0.034	0.033
9	0.055	0.049
10	0.028	0.024
11	0.033	0.027
12	0.044	0.045

Three checks were made on the sulfur content for welder "Z" (test nos. 1, 2, 3). The sulfur percentages were calculated to be 0.035, 0.053 and 0.060. However, by microanalysis methods, the values were 0.053, 0.086 and 0.094% sulfur, respectively. These latter values appear to be unreasonably high, based on the undiluted weld metal and base plate analyses. The deviation here is considerable, but it should be noticed that at least there is agree-

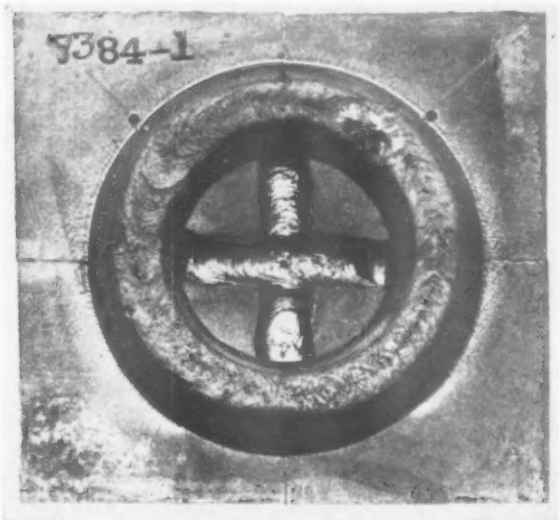

Fig. 2 Typical appearance of cracks in segmented circular-groove specimen. Approximately full size

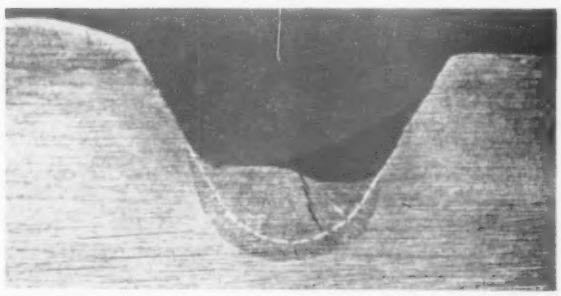

Fig. 3 Photomacrograph of a cross section from a segmented circular-groove test specimen

The area below the dotted line relative to the total weld bead area represents the proportion of base metal dilution. Note the crack extending from the top of the weld bead. Enlarged about X 1 1/2

Table 2—Nondilution Chemical Aslainys of Weld Metals

Electrode	C	Mn	Si	S	P	Cr	Ni	Cb + Ta	N	Mo*	Cu*
						%					
7381	0.084	1.49	0.29	0.014	0.022	18.79	12.91	0.87	0.039*	0.02	0.05
7382	0.121	1.52	0.48	0.013	0.018	18.95	12.91	0.82	0.044*	0.02	0.05
7384	0.090	1.57	0.33	0.012	0.019	18.93	12.72	0.92	0.040*	0.02	0.05
7453	0.095	5.45	0.33	0.012	0.018	18.59	12.35	0.82	0.040	0.20	0.05
7454	0.092	3.20	0.31	0.009	0.013	18.42	12.54	0.89	0.038	0.20	0.05
7455	0.093	2.05	0.32	0.011	0.014	18.68	12.80	0.75	0.042	0.20	0.05
7471	0.087	1.53	0.33	0.013	0.017	19.09	13.33	0.72	0.039	0.02	0.05
7472	0.116	1.32	0.45	0.013	0.020	19.09	13.21	0.69	0.044	0.02	0.05
7475	0.096	5.04	0.37	0.012	0.023	18.48	12.99	0.94	0.037	0.02	0.05
7513	0.058	3.55	0.33	0.013	0.013	19.87	13.15	0.90	0.081	..	..
7520	0.058	4.80	0.27	0.011	0.013	19.66	13.31	0.74	0.080	..	..
7530	0.068	5.02	0.26	0.017	0.011	19.69	13.09	0.53	0.060	..	..
7534	0.071	4.73	0.22	0.012	0.016	19.97	13.31	0.80	0.077	..	..
7535	0.085	4.68	0.24	0.014	0.021	19.78	13.27	0.82	0.071	..	..
7536	0.053	4.62	0.28	0.013	0.018	19.97	13.27	0.89	0.081	..	..
7537	0.059	4.59	0.31	0.012	0.020	19.96	13.30	0.54	0.078	..	..
7543	0.064	4.47	0.49	0.014	0.018	20.11	13.09	0.71	0.077	..	..
7544	0.062	4.41	0.64	0.009	0.018	20.11	13.20	0.82	0.085	..	..
7554	0.113	4.83	0.25	0.009	0.008	19.78	13.03	0.62	0.084	..	..
8335	0.089	1.47	0.77	0.017	0.049	18.72	12.96	0.95	..	0.02	0.05
8476	0.081	1.31	0.27	0.075	0.022	18.60	13.32	0.49	0.057	0.02	0.05
8743	0.076	1.42	0.34	0.021	0.035	18.92	12.85	0.88	0.039	0.02	0.05
8749	0.078	1.31	0.33	0.066	0.019	18.54	13.02	0.52	0.049	0.02	0.05
8753	0.081	1.34	0.35	0.018	0.056	18.90	12.86	0.71	0.041	0.02	0.05
8754	0.082	1.39	0.32	0.017	0.024	18.89	12.82	0.74	0.041	0.02	0.05
8756	0.072	1.34	0.38	0.043	0.018	18.80	12.83	0.61	0.053	0.02	0.05
8844	0.078	1.42	0.60	0.019	0.030	18.89	12.91	0.86	0.045	0.02	0.05
8845	0.081	1.42	0.51	0.021	0.036	18.86	12.76	0.83	0.045	0.02	0.05
8846	0.080	1.50	0.59	0.019	0.063	18.80	12.76	0.94	0.062	0.02	0.05
8847	0.080	1.44	0.71	0.019	0.028	18.73	12.87	0.90	0.039	0.02	0.05
8848	0.079	1.42	0.74	0.018	0.035	18.84	12.98	0.81	0.039	0.02	0.05

* Estimate, based on core wire analyses.

Table 3—Calculated Weld Bead Chemistry for Welder X

Average weld metal dilution by welder X = 32%

% of element A in weld bead = (0.32) (% of element A in base material) + (0.68) (% of element A in nondiluted weld metal)

Example: For test No. 19, % Mn in weld bead = (0.32) (1.31) + (0.68) (3.20) = 2.595

Test no.	Base plate	Electrode	C	Mn	Si	S	P	Cr	Ni	Cb + Ta	N
							%				
1	21	7471	0.0899	1.536	0.484	0.0114	0.0189	18.520	12.504	0.771	0.0300
2	20	7471	0.0841	1.494	0.317	0.0120	0.0189	18.693	12.284	0.699	0.0355
3	8	7471	0.0849	1.543	0.420	0.0124	0.0206	18.568	12.576	0.749	0.0400
4	12	7471	0.0776	1.450	0.378	0.0117	0.0167	18.965	12.527	0.694	0.0332
5	19	7471	0.0781	1.594	0.404	0.0114	0.0196	19.221	12.618	0.768	0.0364
6	17	7471	0.0832	1.459	0.359	0.0140	0.0186	18.597	12.434	0.733	0.0310
7	4	7471	0.0780	1.459	0.372	0.0152	0.0186	18.767	12.565	0.733	0.0336
8	14	7471	0.0761	1.517	0.416	0.0108	0.0170	18.901	12.088	0.694	0.0348
9	13	7471	0.0745	1.610	0.432	0.0108	0.0173	18.872	12.447	0.822	0.0304
10	4	7381	0.0758	1.432	0.344	0.0156	0.0220	18.563	12.280	0.835	0.0336
11	4	7384	0.0801	1.487	0.372	0.0146	0.0200	18.658	12.150	0.872	0.0342
12	4	7382	0.1012	1.453	0.474	0.0152	0.0189	18.672	12.276	0.804	0.0370
13	8	7472	0.1042	1.400	0.501	0.0124	0.0227	18.568	12.491	0.732	0.0434
14	12	7472	0.0970	1.307	0.460	0.0117	0.0187	18.965	12.442	0.677	0.0366
15	13	7472	0.0939	1.467	0.514	0.0108	0.0194	18.872	12.362	0.805	0.0338
16	14	7472	0.0955	1.374	0.498	0.0108	0.0190	18.901	12.003	0.677	0.0382
17	15	7472	0.0929	1.434	0.552	0.0136	0.0187	18.847	12.167	0.782	0.0363
18	4	7455	0.0821	1.813	0.365	0.0139	0.0166	18.488	12.205	0.756	0.0356
19	4	7454	0.0814	2.595	0.358	0.0125	0.0159	18.311	12.028	0.852	0.0329
20	4	7453	0.0835	4.125	0.372	0.0146	0.0193	18.427	11.899	0.804	0.0342
21	4	7475	0.0838	3.846	0.399	0.0146	0.0229	18.352	12.334	0.882	0.0322
22	8	7513	0.0651	2.916	0.420	0.0124	0.0179	19.099	12.454	0.874	0.0685
23	8	7520	0.0650	3.763	0.379	0.0110	0.0176	18.956	12.559	0.766	0.0678
24	8	7530	0.0719	3.916	0.372	0.0151	0.0165	18.976	12.413	0.623	0.0542
25	8	7534	0.0740	3.719	0.345	0.0117	0.0199	19.167	12.563	0.806	0.0658
26	8	7535	0.0832	3.685	0.358	0.0130	0.0233	19.038	12.536	0.820	0.0617
27	8	7536	0.0617	3.644	0.386	0.0124	0.0213	19.167	12.536	0.868	0.0685
28	8	7537	0.0658	3.624	0.406	0.0117	0.0227	19.160	12.553	0.630	0.0665
29	8	7543	0.0692	3.542	0.528	0.0132	0.0213	19.262	12.413	0.745	0.0658
30	8	7544	0.0679	3.501	0.630	0.0093	0.0213	19.245	12.488	0.820	0.0712
31	8	7554	0.1025	3.787	0.365	0.0096	0.0145	19.038	12.372	0.684	0.0706

ment as to the high level of sulfur content.

Statistical Study of Cracking

A series of equations was developed in an attempt to relate composition factors to the actual percent cracking (see Table 5) in the segmented circular-groove test.

After a number of preliminary studies, it was recognized on the basis of statistical analysis that the best fit of the data would be obtained by inserting the carbon and manganese variables as inverse functions. The other elements appeared to be first order in their effects. The form of equation finally selected for the statistical analysis was:

$$\%\ \text{cracking} = b_0 + b_1(1/\text{C}) + b_2(1/\text{Mn}) + b_3(\text{Si}) + b_4(\text{S}) + b_5(\text{P}) + b_6(\text{Ni}) + b_7(\text{Cr}) + b_8(\text{Cb} + \text{Ta}) + b_9(\text{N})$$

The numerical values and the signs of the "b" coefficients, which are slope factors, were computed using a Univac computer.

The test data for welders "X" and "Z" were analyzed together to obtain a single equation relating chemical composition to measured percent cracking ranging from 0 to 100%. The coefficients and the constant obtained are presented at the top of Table 6. Negative signs appear in front of the crack inhibitors and the positive signs in front of the crack promoters as "reported" by the Univac computer, with the exception of carbon and manganese which vary inversely with the percent cracking.

By using this formula and the weld bead chemistry from Tables 3 and 4, the calculated values of percent cracking which are listed in Table 6 were determined. For example, the calculation for welder "X" in test No. 21 was:

$$\%\ \text{cracking} = -133.6 + \frac{6.44}{0.0838} + \frac{43.1}{3.846} + 1.8(0.399) + 384\,(0.0146) + 2295(0.0229) + 9.98(12.334) - 4.48\,(18.352) - \frac{28.8(0.882) - 487(0.0322)}{}$$

$$\%\ \text{cracking} = 13.4$$

A comparison of the calculated percent cracking with the actual measured values (recorded in Table 6) reveals a definite correlation. That is, the percent cracking can be predicted by knowing the chemical analysis of the weld bead. The accuracy of this prediction, estimated by considering the distribution of the respective errors, is ±8 percentage points. This means that the differences between the observed percent cracking and the calculated values will have a standard deviation of 8%. In other words, the frequency of these differences will occur in a pattern similar to the normal frequency curve (Fig. 4), where it is defined that roughly 68% of the total errors will be within a ±8 percentage points difference. Similarly 90% of the total errors will be within a ±13 percentage points difference. This quantity is a statistical measure of reliability of the equation used in calculating cracking as a function of composition.

Cracking Effect of Elements Which Were Intentionally Varied

Element	*Effect of increasing amount on cracking*	*Slope factor*	*Range of variation, %*	*Calculated % cracking variation*
C	Decreases	6.44/C	0.062–0.104	42.0
Mn	Decreases	43.1/Mn	1.31–4.13	22.4
Si	Increases	1.8 Si	0.32–0.73	0.7
S	Increases	384 S	0.009–0.060	19.6
P	Increases	2295 S	0.014–0.055	94.1

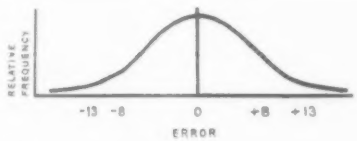

Fig. 4 Normal frequency curve

An alternate graphic picture of the accuracy of the previously mentioned formula is presented in Fig. 5. The diagonal line is the $X = Y$ line, i.e., if a test point falls on this line, the actual and calculated cracking percentages are equal.

Discussion

The full effect of a specific element on cracking tendency depends on two items. First, its *potency* as a crack promoter (or inhibitor) and secondly, the *range* of variation (chemical analysis). The table that follows is presented to:

1. Illustrate the potency of the specific elements by means of the "Slope Factor." (See third paragraph, first column on this page and equation in Table 6.)
2. Indicate the "Range of Variation" for each element.
3. Point out the combined effect of Items 1 and 2 by means of the "Calculated % Cracking Variation."

The "Calculated % Cracking Variation" column was obtained by substituting into the "Slope Factor" the range covered by each element. That is, the calculations for each element were made with the assumption that that element was varied over its complete range while all other elements remain at constant values. For sulfur, for example, the calculation is as follows: 384(0.060) − 384(0.009) = 19.6.

The last column of the previous table permits one to understand more readily than by the use of the mathematical formula the significance of each element. As carbon was increased from 0.062 to 0.104% the cracking was diminished 42%; increasing manganese from 1.31 to 4.13 had the effect of decreasing cracking by 22.4%. The effect of the remaining elements which influence cracking in direct proportion to their amount can be expressed as follows:

For every 0.10% increase in silicon, cracking increases less than 0.2%.

For every 0.010% increase in sulfur, cracking increases 3.8%.

For every 0.010% increase in phosphorus, cracking increases 23.0%.

The isolated effects of carbon and manganese are shown graphically in Fig. 6. With the manganese content at approximately 1.46% and all other elements at standard levels (except for high nickel), the amount of cracking in fully austenitic modified Type 347 weld metal can be substantially reduced by increasing the carbon content. Similarly, with carbon at the 0.083% level, additions of manganese reduce cracking. The high manganese weld metal is seen to be much less crack sensitive. In Fig. 7 the percent cracking is plotted as a function of the phosphorus content and also as a function of the sulfur content.

It should be remembered that the influence of chromium, nickel, columbium and nitrogen was indicated by the statistical analysis on samples in which the percent variation was small (see above table). Notice that these data

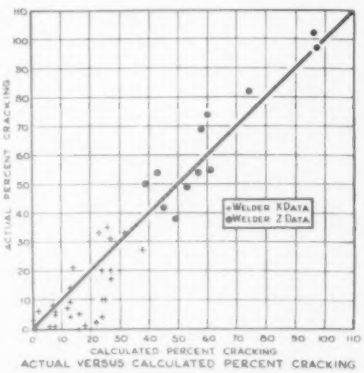

Fig. 5 A comparison of the test data with the $X = Y$ line

The welder Z cracking values are at higher leve because the electrodes employed were the high phosphorus and high sulfur series.

Table 4—Calculated Weld Bead Chemistry for Welder Z

Average weld metal dilution by welder Z = 24%

% of element A in weld bead = 0.24 (% of element A in base material) + (0.76) (% of element A in nondiluted weld metal)

Example: For test No. 8, % P in weld bead = (0.24)(0.0283) + (0.76)(0.036) = 0.0342

Test no.	*Base plate*	*Electrode*	% *C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*Cb + Ta*	*N*
1	8	8756	0.0740	1.395	0.435	0.0353	0.0205	18.478	12.385	0.660	0.0504
2	8	8749	0.0786	1.372	0.397	0.0527	0.0212	18.281	12.529	0.596	0.0469
3	8	8476	0.0808	1.372	0.352	0.0596	0.0235	18.326	12.757	0.598	0.0534
4	8	8754	0.0812	1.433	0.390	0.0155	0.0250	18.547	12.377	0.759	0.0412
5	8	8743	0.0770	1.456	0.405	0.0186	0.0334	18.570	12.400	0.866	0.0397
6	8	8753	0.0808	1.395	0.412	0.0163	0.0494	18.554	12.408	0.736	0.0412
7	8	8844	0.0786	1.456	0.602	0.0170	0.0296	18.547	12.446	0.850	0.0443
8	8	8845	0.0805	1.456	0.534	0.0186	0.0342	18.529	12.332	0.828	0.0440
9	8	8846	0.0797	1.517	0.595	0.0170	0.0547	18.478	12.332	0.911	0.0572
10	8	8847	0.0801	1.471	0.686	0.0170	0.0281	18.425	12.415	0.881	0.0397
11	8	8848	0.0789	1.456	0.709	0.0163	0.0334	18.509	12.499	0.812	0.0397
12	8	8335	0.0869	1.494	0.732	0.0155	0.0440	18.418	12.484	0.919	0.0400*

Core wire chemical analyses

Electrodes	% *C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*N*	*Mo*	*Cu*
7381–7475 and 8335–8848	0.070	1.59	0.35	0.010	0.013	19.60	13.24	0.019	0.02	0.05
7513–7554	0.039	4.52	0.25	0.014	0.016	21.08	13.24	..	..	..

* Estimate.

Table 5—Measured Length of Bead Cracks and Actual Percent Cracking

$$\%\ \text{Cracking} = \frac{\text{Measured length of bead cracks (excluding crater cracks)}}{\text{Circ. of 2 in. diam circle} - \text{length of circ. occupied by the crater}} \times 100$$

Example: Test No. 15 for welder X, actual percent cracking $= \frac{0.515}{6.28 - 0.62} \times 100 = 9.1$

Welder X				*Welder Z*			
Test no.	*Length of bead crack, in.*	*Length of crater*	*Bead cracking, %*	*Test no.**	*Length of bead crack, in.*	*Length of crater*	*Bead cracking, % avg.*
1	0	0.60	0	1-1	2.80	0.62	49.5
2	0.125	0.60	2.2	1-2	3.60	0.63	63.6 } 54.2
3	0.560	0.57	9.8	1-3	2.80	0.62	49.5
4	0.950	0.63	16.8	2-1	2.78	0.63	49.2 } 49.3
5	1.150	0.56	20.1	2-2	2.80	0.62	49.5
6	1.760	0.64	31.2	3-1	3.34	0.64	59.2
7	1.860	0.64	33.0	3-2	2.65	0.63	46.9 } 53.9
8	1.890	0.61	33.4	3-3	3.14	0.64	55.6
9	1.950	0.64	34.6	4-1	3.41	0.62	60.3
10	1.495	0.64	26.5	4-2	2.74	0.63	48.5 } 49.8
11	1.130	0.63	20.0	4-3	2.30	0.63	40.7
12	0.035	0.45	0.6	5-1	3.34	0.53	58.1
13	0	0.57	0	5-2	2.19	0.62	38.7 } 55.3
14	0.275	0.60	4.8	5-3	3.90	0.64	69.2
15	0.515	0.62	9.1	6-1	5.47	0.63	96.8
16	0.590	0.56	10.3	6-2	5.03	0.63	89.0 } 96.9
17	1.160	0.70	20.8	6-3	5.91	0.65	105.0
18	0.790	0.60	13.9	7-1	1.39	0.63	24.6
19	0.330	0.59	5.8	7-2	2.70	0.63	47.8 } 38.1
20	0.160	0.56	2.8	7-3	2.37	0.63	42.0
21	0.200	0.72	3.6	8-1	4.24	0.63	75.1
22	0.460	0.60	8.1	8-2	3.86	0.63	68.4 } 68.6
23	0.290	0.70	5.2	8-3	3.51	0.63	62.2
24	0.035	0.45	0.6	9-1	5.45	0.63	96.5
25	0	0.48	0	9-2	5.66	0.62	100.0 } 101.9
26	0	0.53	0	9-3	6.17	0.62	109.1
27	0.060	0.82	1.1	10-1	1.62	0.64	28.7
28	0.230	0.53	4.0	10-2	2.78	0.64	49.4 } 42.2
29	0.370	0.58	6.5	10-3	2.73	0.63	48.4
30	0.320	0.46	5.5	11-1	3.80	0.64	67.5
31	0	0.51	0	11-2	4.61	0.61	81.4 } 73.8
				11-3	4.10	0.62	72.5
				12-1	4.85	0.64	86.0
				12-2	4.18	0.63	74.0 } 82.4
				12-3	4.94	0.63	87.3

* Numbers after dashes indicate the number of repeat tests.

Table 6—Calculated Percent Cracking in Comparison with the Actual Measured Values

$$\%\ \text{Cracking} = 133.6 + \frac{6.44}{C} + \frac{43.1}{Mn} + 1.8\,Si + 384\,S + 2295\,P + 9.98\,Ni - 4.48\,Cr - 28.8\,(Cb + Ta) - 487\,N$$

Test no.	Calculated % cracking	Actual % cracking	Difference
	Welder X		
1	20.2	0	+20.2
2	22.4	2.2	+20.2
3	24.8	9.8	+15.0
4	26.9	16.8	+10.1
5	26.7	20.1	+6.6
6	27.1	31.2	−4.1
7	32.1	33.0	−0.9
8	22.8	33.4	−9.6
9	25.9	34.6	−8.7
10	38.1	26.5	+11.6
11	24.3	20.0	+4.3
12	7.9	0.6	+7.3
13	16.3	0	+16.3
14	16.4	4.8	+11.6
15	13.3	9.1	+4.2
16	24.2	10.3	+13.9
17	13.8	20.8	−7.0
18	12.9	13.9	−1.0
19	2.2	5.8	−3.6
20	0.3	2.8	−2.5
21	13.4	3.6	+9.8
22	7.4	8.1	−0.7
23	7.6	5.2	+2.4
24	6.2	0.6	+5.6
25	0.5	0	+0.5
26	1.2	0	+1.2
27	18.2	1.1	+7.1
28	23.5	4.0	+19.5
29	11.6	6.5	+5.1
30	7.9	5.5	+2.4
31	0	0	0
	Welder Z		
1	43.4	54.2	−10.8
2	53.0	49.3	+3.7
3	57.4	53.9	+3.5
4	39.0	49.8	−10.8
5	61.0	55.3	+5.7
6	97.3	96.9	+0.4
7	49.0	38.1	+10.9
8	57.9	68.6	−10.7
9	95.5	101.9	−6.4
10	45.4	42.2	+3.2
11	60.4	73.8	−13.4
12	74.4	82.4	−8.0

indicate that nitrogen is a rather strong crack inhibitor.

When evaluating the results of this statistical investigation it should be remembered that the method of determining weld bead chemistry is an approximation. It is not claimed that the individual elements are uniformly distributed in the weld bead. In addition, the "dilution" method of determining the chemistry of the weld bead is at best a good approximation because human variables, which cannot be fully controlled, no doubt result in a varying amount of dilution within a single circular-groove specimen and also from specimen to specimen.

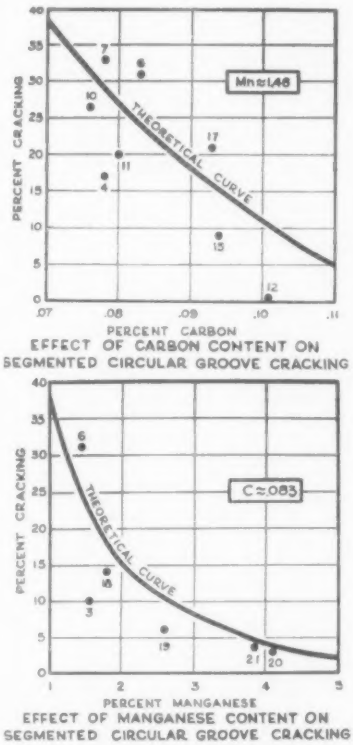

Fig. 6 The effect of carbon and manganese variations on the measured segmented circular-groove cracking of fully austenitic Type 347 weld metal

All elements but carbon were at standard levels for the top graph (except for high nickel). In like manner, all elements with the exception of manganese were at standard levels for the bottom graph. The numbers beside the points indicate welder "X" test numbers. The theoretical curve is a plot of the percent cracking equation (see Table 6) using average values for the points shown for all elements other than the major variable (carbon or manganese).

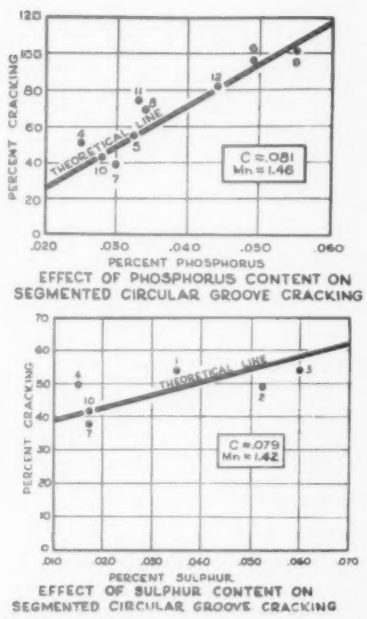

Fig. 7 The effect of phosphorus and sulfur content on the measured segmented circular-groove cracking of fully austenitic Type 347 weld metal at standard carbon and manganese levels

The numbers beside the points indicate a welder "Z" test number. The theoretical line is a plot of the percent cracking equation (see Table 6) using average values for the points shown for all elements other than the major variable (phosphorus or sulfur).

The reproductiveness of cracking in duplicate specimens has, in general, been good. However, the reproductiveness of values in Test No. 7 for welder "Z" (see Table 5) was poor, thus illustrating that the human variable was once again a factor.

Despite the many approximations and assumptions introduced into this investigation, statistically valid relationships have been derived, but because of known sources of errors, no claim is made for the numerical accuracy of the individual factors shown in the mathematical equations. The qualitative relationship of the elements can be the basis for drawing sound conclusions. The effort which has been expended on this study is justified if it guides the research metallurgist in his continuing search for less crack-sensitive fully austenitic weld metals.

Cracking Effect of Elements Which Were Unintentionally Varied

Element	Effect of increasing amount on cracking	Slope factor	Range of variation, %	Calculated % cracking variation
Cr	Decreases	4.48 Cr	18.28–19.26	4.4
Ni	Increases	9.98 Ni	11.89–12.75	8.6
Cb + Ta	Decreases	28.8 (Cb + Ta)	0.60–0.92	9.2
N	Decreases	487 N	0.030–0.071	20.0

Conclusions

The following conclusions are offered concerning the effects of the individual elements on cracking tendency of fully austenitic modified Type 347 weld metal in the as-deposited condition. Cracking due to, or during, heat treatment has not been explored.

Elements That Were Intentionally Varied

Effect of Carbon and Manganese. The

statistical analysis which has been presented has pointed to carbon and manganese as potent cracking inhibitors. Since each of these elements was varied over a rather wide range, their indicated effects are believed to be assuredly valid.

Effect of Phosphorus. The results of this investigation, which indicate that phosphorus was the most potent crack promoter, are felt to be valid since this element was varied over a wide range.

Effect of Sulfur. Sulfur was also widely varied. The relationship between increasing amounts of sulfur and greater cracking tendency is believed to be dependably accurate.

Effect of Silicon. A somewhat surprising result was found in the study of the effect of silicon on cracking. The range of variation was appreciable, yet only a very slight increase in cracking tendency was recorded with increasing amounts of silicon.

The work of others on different fully austenitic alloys which has indicated that silicon is a major factor in promoting the cracking of fully austenitic weld metal, is by no means being repudiated. Our work dealing with Type 347 simply has not verified these findings.

Elements That Were Not Intentionally Varied

Effect of Chromium. The range of variation of this element was very small since it was not a planned variable. The indicated slightly beneficial effect should therefore be considered tentative.

Effect of Nickel. Since nickel was not an intentionally varied element, its full range of variation was very small. However, the statistical approach used in this investigation indicated that increasing amounts of nickel tended to promote cracking. This observation should not be accepted as fact until a wider range is investigated.

Effect of Columbium. The role of columbium as a mild crack inhibitor, as revealed by the statistical study, may be justified in the range of variation which occurred. Note, however, that this range is at a high level for columbium. Thus no information has been obtained concerning possible effects of columbium when it is increased from 0%.

Effect of Nitrogen. Since nitrogen varied over a narrow range due to the fact that only residual amounts were present, the apparently strong effect of this element as a crack inhibitor should be taken into account with heedful reservation. In general, the higher percentages of nitrogen were present when the manganese was also high.

Additional Comments

It should be remembered that the above conclusions concerning the effect of specific elements on cracking tendency are admittedly simplified. Complications result when ratios between certain elements change, i.e., the effect of sulfur content on percent cracking may be less pronounced at higher manganese levels. Other relationships such as carbon-to-silicon, and columbium-to-silicon may cloud the one-by-one method of analysis.

Actually, a considerable amount of work has been accomplished on two fully austenitic modified Type 347 weld-metal compositions ("C" and "H") in the course of a program sponsored by the Atomic Energy Commission.[8–12] One weld metal was fully austenitic by virtue of high carbon content (composition C) and the other as a result of high manganese (composition H). The freedom of these compositions from weld-metal cracking confirms the importance of carbon and manganese, as deduced from the statistical analysis.

The cracking tendency of fully austenitic modified Type 347 weld metal can be minimized by judicious control of the chemistry. In addition, selection of the optimum composition is now closer to reality through the use of the statistically derived relationship which presents cracking as a function of weld-metal chemistry.

Well accepted means of obtaining a crack-resistant fully austenitic weld metal, such as increasing the carbon and/or manganese, have been confirmed. The advisability of maintaining the phosphorus, sulfur and silicon at standard low levels has been verified although the indicated effect of the latter element appears to be slight. In particular, this investigation has pointed out the primary importance of maintaining the phosphorus content as low as possible.

The indicated detrimental effect of increasing amounts of nickel and the beneficial effects of increasing the chromium, columbium and nitrogen percentages are indeed interesting observations. As has been noted, the ranges of nickel, columbium, chromium and nitrogen were small. Further work must be done in order to firmly establish the effect of these elements on the cracking tendency.

Acknowledgment

This program was directed and supervised by the Advisory Committee for Welding of Stainless Steels. The cracking tests were supervised by L. K. Poole.

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MECHANISM OF MICROCRACKING IN MILD-STEEL WELDING

Research program shows how far the problem of microcracking extends to electrodes available in Canada and explores more fully the role played by nonmetallic inclusions in the phenomenon

BY K. WINTERTON

SYNOPSIS. Microcracking, characteristic of metal-arc mild-steel weld metal, has been observed in the weld metal from a number of different electrodes available in Canada. Considerably less microcracking was found with low hydrogen basic-coated types.

The effect of several variables on the incidence of microcracking has been examined and discussed. Special attention has been given to the types of nonmetallic inclusions present and to their role in microcracking.

A general theory is put forward to account for microcracking (and the closely related phenomenon of halo-formation) in terms of the accumulation of hydrogen under pressure in pre-existent flaws, specifically incipient hot cracks and also misfits at the boundaries of nonmetallic inclusions. The phenomenon of hydrogen diffusing out of weld metal from these exit points is illustrated.

Introduction

The phenomenon of microcracking, also known as fissuring, in metal-arc mild-steel weld metal is concerned with the formation of large numbers of small cracks in the weld metal from most types of electrodes under conditions of rapid cooling. They have received little attention because they are not readily observed by conventional methods of microscopical examination because:

(*a*) The microcracks are oriented and show up mainly in longitudinal sections, very few being seen in the transverse sections which are usually examined.

(*b*) Special methods of polishing and etching are needed to reveal the cracks.

The author has little doubt that the occurrence of haloes or fish eyes in as-deposited weld metal is simply a manifestation of the action of external tensile stresses on microcracks containing hydrogen under pressure. This aspect of the matter is given more attention under the discussion of results.

Previous work has shown that microcracks are associated with hydrogen content. The latter is at a dangerous level in many electrodes but not in all. The amount retained at about 200° F depends on the cooling conditions, and this decides whether or not microcracking will occur. Usually, fairly rapid cooling rates are needed to obtain cracking.

Rapid cooling rates are associated with (1) small heat input, e.g., light electrode gage, low current, short runs, tack welding, (2) massive plates or blocks and (3) welding at low ambient temperatures (i.e., low plate temperature).

It is this third factor which gives the danger of microcracking a special importance to the Canadian welding scene.

Fifteen electrodes were chosen from those available for mild-steel arc welding in Canada; these were mostly of American manufacture. The list covers most of the different types of coating used. No special efforts were made to select the most popular electrode types or brand names.

The intention of the present work was to see how far the problem of microcracking extended to electrodes available in Canada, and also to explore further the role of nonmetallic inclusions in the phenomenon.

Previous Work

The presence of microcracks in deposited mild-steel weld metal was first noticed by Flanigan.[1] The welds had been quenched soon after deposition, and were made as part of an investigation into the effect of hydrogen and cooling rates on weld ductility. Bland,[2] investigating an electrode specification permitting quenching between layers of a multi-pass weld, showed that microcracks are liable to form in a weld quenched soon after completion (20 sec) but not if a sufficient time elapsed before quenching (10 min). Sufficiently-high rates of cooling could be obtained by making a weld on steel pre-cooled to low temperatures or on a massive steel block. These findings were confirmed later by Flanigan and Kaufman.[3]

Bland[2] noticed that microcracks were found in longitudinal sections but not in transverse sections of welds, and that they were frequently at the boundaries of the columnar grains. With hydrogen-rich welds, rate of cooling, or more generally the cooling program, controls the level of hydrogen content remaining in the weld. According to Bland,[2] the amount retained decides whether or not cracking will occur. He gave the critical level as 10–30 cc hydrogen per 100 g of weld metal.

Rollason and Roberts[4] confirmed some of Bland's findings and reported on the critical sizes of steel plates required to produce cracking for various electrode sizes. They suggest that for a given electrode type there is a critical rate of cooling and that this may be conveniently interpreted sometimes in terms of a critical thickness of heat-affected zone.

Absence of cracking in single-pass low-hydrogen weld deposits reported by Bland[2] was confirmed by Rollason and Roberts,[4] though they found some cracking in multi-pass deposits due to the buildup of hydrogen content in the later passes. This was confirmed by later work.[5]

Rollason and Roberts[4] believed that nitrogen content helped to cause microcracking but other workers have been unable to confirm this. The same authors have discussed the influence of manganese and alloying additions.

Flanigan and Kaufman[3] showed that microcracking caused permanent damage to bend-test ductility, tensile strength and fatigue strength.

With regard to the detection of microcracks, these authors pointed out that the defects are too fine to be discovered by the standard methods of crack detection and that microscopical examination is necessary. They favored electropolishing, believing that mechanical polishing followed by deep etching results in a surface appearance in which it is difficult to distinguish the microcracks from elements of the background

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structure. Moreover they found that microcracks were much more numerous in longitudinal sections than in the more commonly examined transverse sections, typical results being as follows:

(*a*) Transverse section—5 cracks per section

(*b*) Vertical section (in flat downhand weld) dividing weld symmetrically—75 cracks per in. length of section.

(*c*) Horizontal section (in flat downhand weld) parallel to plate surface—600 cracks per in. length of section.

Flanigan and Micleu[5] found that preheating at quite low temperatures could have a marked beneficial influence depending on the conditions of heat input, etc. The same authors showed that the occurrence of microcracking could not be correlated with the hardness of the weld deposit.

Tests with various kinds of cooling program showed that microcracking normally occurred at about 150–200° F. Also, some microcracking could be produced by sufficiently rapid cooling from temperatures as low as 400° F, provided that cooling rates at the higher temperatures (1500–400° F) were not too slow. Flanigan and Micleu[5] conclude that the beneficial effect of moderate preheating derives in the main from the slowing up of cooling rates at relatively low temperatures.

Christensen and Rose[6] have confirmed some of the previous work and have examined in greater detail the distribution of microcracks in welds. Values quoted by them for hydrogen content seem rather high. At a temperature of 250° C they found that progressive reduction in the amount of cracking occurred more slowly than would be expected from the rate of loss of hydrogen.

Warren and Vaughan[7] found that microcracks were often associated with nonmetallic inclusions, though magnifications of 1000 X or more were sometimes necessary to detect the latter.

These authors point out the dangers of microcracks as potential initiators of brittle fracture. In one case, severe longitudinal weld cracking occurred 48 hr after welding in a Lehigh test, under the combined action of longitudinal residual stress and the microcracks present. Also at loads of about yield-point value weld metal containing microcracks begins to "creep" due to the spreading of cracks and finally it breaks. These authors showed that brittle fracture could be simulated in large plates containing a long butt-weld solely under the action of welding stresses, with a fine saw-cut to represent a long microcrack extending into the heat-affected zone. Microcracks have also been found in a weld taken from near the source of a catastrophic brittle failure of an oil storage vessel.

Materials

The blocks for the welding tests were cut from rolled mild-steel bar of $2^1/_2$ x 1 in. rectangular section. The composition of the steel was as follows: carbon 0.21, manganese 0.55, silicon 0.164, sulphur 0.011, phosphorus 0.021.

The smaller blocks for the hydrogen determinations were cut and ground from mild-steel bar of 1 in. x $^3/_{16}$ in. rectangular section. The composition of the steel was as follows: carbon 0.26, manganese 0.50, silicon 0.098, sulphur 0.014, phosphorus 0.026.

Fifteen electrodes were used in the tests. These are given in Table 1, together with typical composition and properties in the as-deposited and stress-relieved condition.

Method of Investigation

Testing for diffusible hydrogen content was done at room temperature by a method described fully previously[8] and which is briefly as follows. A single short bead (2 in.) was laid from the test electrode onto a small steel block 2 in. x 1 in. x $^3/_{16}$ in. The weld was laid at 100 amp dc, using reverse polarity, unless this was contrary to the manufacturers' recommendations. Immediately after welding, the specimen was quenched in water and transferred to a tank of glycerine. These operations were effected as rapidly as possible, the time elapsing between the end of welding and the immersion of the specimen in glycerine being 10 to 20 sec. The hydrogen was collected by displacement using a glass funnel inserted in the mouth of an inverted 2-cc burette.

Table 1—Deposit Composition and Mechanical Properties of Test Electrodes (typical)

								Mechanical properties					
								As-welded			*Stress relieved*		
Electrode	*AWS/CSA code*	*Type of coating*	*C*	*Mn*	*S*	*P*	*Si*	*TS (psi)*	*YP (psi)*	*ER %*	*TS (psi)*	*YP (psi)*	*ER %*
A	E6010	High cellulose	0.08	0.45	0.03	0.03	0.15	65,000–77,000	53,000–60,000	22–30	60,000–72,000	48,000–56,000	29–37
B	E6010	Sod. silicate	0.07	0.40	0.02	0.02	0.20	67,000		26			
C	E6010		0.08–0.12	0.30–0.50	0.04	0.04	0.15–0.25	62,000–72,000	52,000–62,000	22–28	60,000–65,000	50,000–55,000	26–30
D	E6012	High titania	0.09	0.60	0.03	0.03	0.20				72,000	58,000	33
E	E6012	Sod. silicate	0.08–0.12	0.35–0.45	0.035	0.025	0.10–0.20	68,000–75,000	58,000–65,000	19–25	63,000–70,000	53,000–60,000	23–27
F	E6020	High iron oxide	0.08	0.39	0.03	0.02	0.07	70,500	61,000	29	66,500	57,500	32
G	E6024	High iron powder						90,000	78,000	24	86,000	72,000	23
H	E6024		0.068	0.87	0.14	0.19	0.78	75,000–81,000	68,000–73,000	18–24			
I	E6016	Low hydrogen											
J	E6016	Pot. silicate	0.11	0.48	0.024	0.024	0.47	78,000	69,000	26			
K	E6016		0.07–0.12	0.40–0.60	0.035	0.035	0.40–0.60	72,000	59,000	29	69,000	55,000	34
L	E6016		0.10	0.90	0.03	0.03	0.35	75,000–80,000	60,000–70,000	25–30	70,000–75,000	58,000–65,000	30–40
M	E6016												
N	E8016(?)		0.08	0.85*	...	...	0.37	86,000	77,000	24	82,000	67,000	27
O	E4510	Light dust coating						52,000	...	8			

* Contains in addition 1.25% Cr and 0.50% Mo.

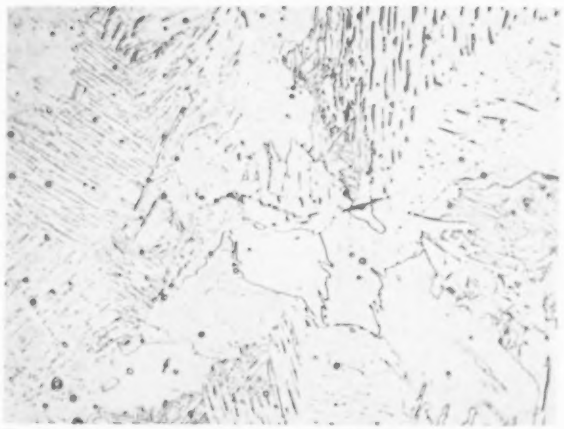


Fig. 1 Microcrack. Etched nital. X 750

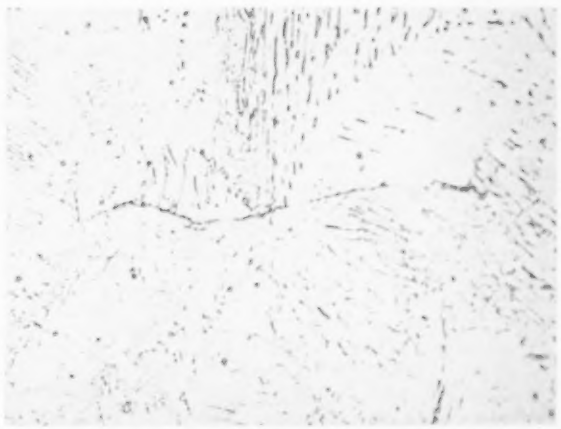


Fig. 2 Microcrack. Etched Noren's reagent. X 750

The deposition of welds for examination for microcracks was done as follows. A short weld bead was made, 3 in. in length, in a groove in a steel block 6 x $2^1/_2$ x 1 in. The groove was cut with a 60° Vee and was $^1/_4$ in. deep. Again the welds were laid at 100 volt dc using reverse polarity unless this was contrary to the manufacturers' recommendations. The block was normally pre-cooled to 0° C with melting ice before test. After welding, the central 1-in. length was cut out by means of two transverse cuts. The excess weld was then removed by grinding flush to the plate surface and continuing the grinding to $^1/_{32}$ in. below the original plate surface. The horizontal weld surface so revealed was examined for microcracks.

It was thought that the block used for the welding tests would be heavy enough to ensure microcrack formation especially when pre-cooled. The purpose of the Vee groove was to sink the weld into the block to increase the biaxial stress condition at the mid-horizontal section. Welding produces longitudinal and transverse residual stresses with the former normally dominant, and it is this stress pattern that is associated with fissure formation. When a bead is deposited on a plate surface the horizontal section richest in microcracks lies a little above the original plate surface. Using a groove it was expected that the richest section would be found a little below the original plate surface and that the stress condition at this position would be enhanced by this means. The technique would also be expected to reduce differences associated with variations in weld penetration.

The sections were polished for microscopical examination by conventional means after which they were etched in Noren's reagent following the practice of Christensen and Rose.[6] Seventy traverses of the complete width of the specimen were made so that the entire area was scrutinized. The magnification was × 480.

The results are then expressed as microcracks per inch length of weld. The above outline of procedure was that normally adopted. Variations are noted in the text which follows.

Results

Etching Reagent

The use of an aggressive, usually aqueous, etchant was found desirable. It may be noted that fissures are very rarely visible in the unetched (mechanically polished) condition. Figure 1 shows a microcrack partially revealed by 2% nital, while Fig. 2 shows the same area after etching in Noren's reagent. One complete section showed 16 cracks per in. length after nital etching, and 206 cracks per in. length after etching in Noren's reagent. The latter was adopted and used for the later examination. The structure is rather poorly revealed by this reagent but for the main purpose of counting microcracks, the reagent appears satisfactory.

Microcrack Density

A brief acquaintance with the technique of microcrack detection and counting, leads to the conclusion that a single microcrack count can be nothing more than a very rough guide to the tendency of an electrode to produce microcracks. The number of microcracks detected depends very much on the surface preparation and etching technique. The number also depends very strongly on the magnification used. At higher magnifications a greater number of small microcracks can be unambiguously distinguished from elements of the structure. At any given magnification, there is always some doubt as to the validity of the smallest

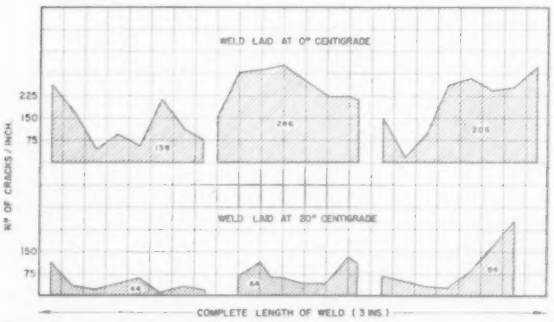


Fig. 3 Variation of microcracks density of two welds laid at different plate temperatures

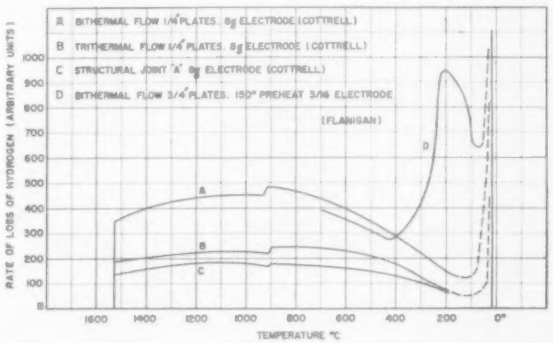


Fig. 4 Derived curves for loss of hydrogen from cooling welds. (The area under the curves represents amount of hydrogen lost)

microcracks. There is no reasonable method of distinguishing between microcracks and small hot-cracks located at the grain boundaries. Aside from these factors the microcracks' density varies markedly from place to place in the structure (Fig. 3). It is not surprising to learn[8] that different observers arrive at different values for the microcrack count even on identical specimens.

In different laboratories, wide variations in technique have been employed and their results may be compared only in a very rough fashion.

Examination of Fig. 3 shows that there may be a slight trend for an increasing density of microcracking at the beginning and end of the bead. This may be noticed in both welds. This is no doubt due to end-effects associated with more rapid cooling rate. The beginning and end are not symmetrical from this point of view and the effect near the beginning is more localized. These effects will depend strongly on the weld geometry and other conditions affecting rate of cooling.

The length of the microcracks varied widely being often 0.01 in. and above, but most commonly about 0.001 in. No special attempt has been made to examine the factors affecting this variation. Neither has any classification according to size been made.

Effect of Plate Temperature

Some results are shown in Fig. 3 for the distribution of microcracks along the length of a complete 3-in. test weld. In this case the test weld was divided into three parts, each 1 in. long, and the surface area of each specimen was traversed completely. Each plot was made by taking the number of microcracks in 10 traverses (0.14 in.) and expressing the result in terms of microcracks/inch length.

The series shown in the upper part of the figure was made from a test weld using an initial plate temperature of 0° C. This may be compared with the

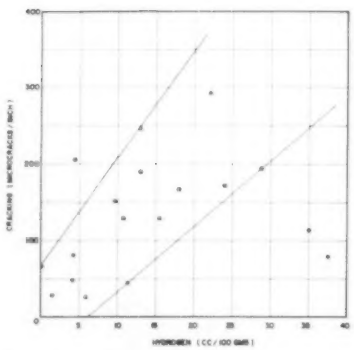


Fig. 5 Relationship between microcracking and hydrogen content

lower series with the plate at ambient temperature (20° C). The effect of this small difference in temperature is quite remarkable, the total microcrack count for the complete sections being respectively 590 and 202.

The effect of relatively small deviations in plate temperatures on low-temperature cooling rates is quite pronounced. Such changes affect considerably the opportunity for the escape of hydrogen. The curves shown in Fig. 4 are of interest in this connection. These are theoretical curves for the loss of hydrogen from cooling welds. Cooling rate data are taken from work by Cottrell[9] and by Flanigan and Micleu.[5] The curves were obtained as follows:

Loss of hydrogen (over a small temperature interval $T_2 - T_1$)

$$= fn\left[C.D\frac{T_2}{T_1}(t_2 - t_1)\right] \qquad (1)$$

where C = average hydrogen concentration, given by the difference between the amount present and the amount in solid solution, averaged over the temperature range $T_2 - T_1$.

Values for solid solubility were obtained from the published information of Sieverts[10] and Martin.[11] An initial supersaturated value of 40 cc/100 g in the solid iron at 1530° C has been assumed. $D\frac{T_2}{T_1}$ = the diffusivity averaged over the temperature range $T_2 - T_1$.

$$D = K/d\ p^m e^{-Eo/2kT} \qquad (2)$$

where

d = distance
p = pressure difference
T = absolute temperature
k = Boltzman's constant
K, Eo and m = constants

Substituting the appropriate values for the diffusion of hydrogen in α iron, we obtain:

$$D = ae^{-15000/4T} \qquad (3)$$

where a is a constant.

The time lag $t_2 - t_1$ was obtained from the published curves of Cottrell[9] and Flanigan and Micleu.[5] Values for cooling rate at temperatures in excess of 700° C in the case of the data by Cottrell[9] were obtained by extrapolation using the formula of Rosenthal:[12]

$$R_t = \frac{2\pi kv}{Q}(t - t_o)^2 \qquad (4)$$

where

R_t is the cooling rate at temperature t° C of a bead weld on an infinite flat plate in deg C/sec
k is the thermal conductivity of the steel (cal/cm sec ° C)
Q is the heat delivered to the plate in cal/sec
v is the speed of welding in cm/sec
t_o is the initial plate temperature (° C)

This extrapolation is reasonable since the results obtained by Cottrell[9] show that the Rosenthal relation[12] is obeyed at lower temperatures.

The curves in Fig. 4 have the following implications:

(*a*) In simple welds (without preheating), hydrogen is lost over the entire temperature range from 1530° C to room temperature. As the weld cools,

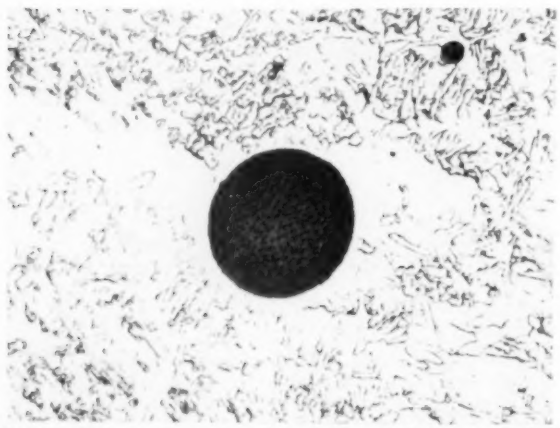


Fig. 6 Inclusion Type A. Etched Noren's Reagent X 500

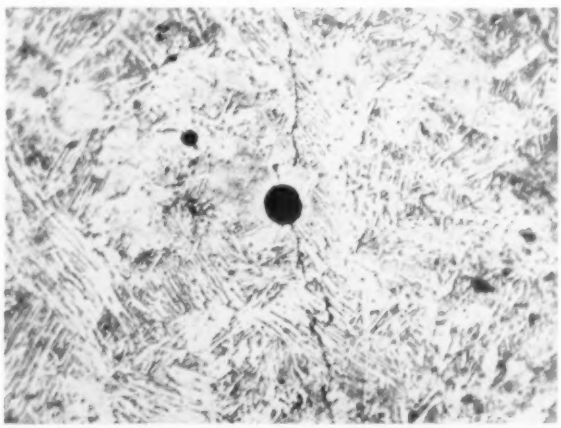


Fig. 7 Microcracking through inclusion. Etched Noren's reagent. X 500

decreasing diffusivity is roughly counterbalanced by the increasing time available.

(*b*) Loss of hydrogen is sensitive to the weld geometry because of the effect on the cooling conditions. A butt weld (Curve A, Fig. 4) would be expected to lose much more hydrogen (perhaps about twice as much) on cooling than a comparable T-joint fillet (Curve B, Fig. 4). The terms "bithermal" and "trithermal" used in Fig. 4 refer to the number of equivalent paths of heat flow, i.e., in this case two and three $\frac{1}{4}$-in. plate sections respectively.

(*c*) The effect of preheating is to permit greater losses of hydrogen at relatively - low temperatures where the cooling rates are most retarded. (See also the comments of Flanigan and Micleu.[5])

The effect of a limited heat sink can be similar to that of preheating. For example, with a large weld on a small steel block, there would be a tendency for the temperature of the combined mass to approach a value T_1. At high temperatures the rate of cooling is governed by the possibilities for heat flow through the conducting steel plates (for a fuller treatment, see Cottrell[9]). At lower temperatures, in the neighborhood of T_1, cooling by convection is dominant. In such a system the effect of the limited heat sink is equivalent to welding on a larger block preheated to T_1.

It would be interesting to establish by experiment the amounts of hydrogen retained in joints of various geometry and degrees of preheat. The factors are complex. Quite-marked variations are likely to occur in normal welding practice.

It should be noted that the data of Fig. 4 and the above remarks are concerned mainly with the *availability* of hydrogen at the low temperatures where microcracking is believed to occur. Flanigan and Saperstein[13] have recently shown that short isothermal treatments at temperatures in the range 1290°–212° F usually suffice to reduce considerably the incidence of microcracking, though it appeared that the lower temperatures (i.e., below 800° F) are more successful for achieving complete immunity. The matter is complicated by the variations in solubility and diffusion of hydrogen in the various phases present in this temperature range, and probably also the retention of hydrogen in retained austenite as in the case of underbead cracking.

Flanigan and Saperstein[13] have also shown that the microcracking tendency is reduced with extremely high rates of cooling *immediately* after welding. Perhaps, in this case, there is insufficient time for hydrogen to diffuse to the points of weakness by the time that critical temperatures are reached (about 212° F). Neither of these findings invalidates a general examination of the thermal factors effecting the availability of hydrogen and, therefore, the potentiality for cracking.

Table 2—Weld Hardness and Microcracking Density

Plate temperature	*First section*		*Second section*		*Third section*		*Average*	
	Cracking	*Hardness*	*Cracking*	*Hardness*	*Cracking*	*Hardness*	*Cracking*	*Hardness*
0° C	138	252*	246	261	206	266	197	259[y]
20° C	44	266	64	261	94	256	67	261[x]

* Each of the values of this type is the average of 7–10 individual results.
[y] Scatter range 227–294 in the individual results.
[x] Scatter range 240–292 in the individual results.

Weld Hardness and Microcrack Density

Because of the effect of rate of cooling, there is an obvious possibility that the hardness of the weld might vary and account for the changes in microcrack density. Hardness tests were therefore made on the welds used for the tests illustrated in Fig. 3. The results are given in Table 2.

The results show clearly that there is no correlation between hardness and the density of microcracking. Similarly, no detailed correlation could be found in the local variations in hardness and microcrack density along the length of the weld. This confirms the findings of Flanigan and Micleu.[5]

Electrode Type

Welding tests were carried out on the range of electrodes using the grooved test block described previously and with an initial plate temperature of 0° C. The middle section (1 in.) only was examined. The results of the counts of microcracks are given in Table 3. It may be noted that some fine cracks were found in the heat-affected zone. These were few in number compared with the density found in the weld metal.

Some microcracks were found in each of the weld deposits from the low-hydrogen basic-coated electrodes. However, the density was far less (26–85 microcracks/inch with one exception*) than in the case of the other types of coated electrodes (114–290 microcracks/in.). Apart from this broad distinction, which confirms the results of previous workers,[2–7] no further conclusions could be made about the effect of electrode coating. The results are discussed further under the heading of hydrogen content and the effect of nonmetallic inclusions.

There is a possibility that the relative freedom from microcracking characteristic of low-hydrogen electrodes is at least partly due to a greater tendency for porosity in the weld metal (usually found except under the closest conditions of control). Hydrogen could be trapped in these pores under relatively

* See footnote to Table 3.

Table 3—Hydrogen, Inclusions and Microcracking

Electrode	*AWS/CSA code*	*Hydrogen, cc/100 g*	*A*	*B*	*C*	*D*	*E*	*Cracking microcracks/in. length*
A	E6010	21·8	5	1			3	290
B	E6010	18·4	5	1	1		5	167
C	E6010	9·7	4	2	1		3	151
D	E6012	13·0	2	4	1		2	190
E	E6012	10·7	2	4			2	129
E	E6012	15·4	2	4			2	129
F	E6020	24·2	7	1	1		3	172
G	E6024	28·9	7	1	1		5	194
H	E6024	34·5	8	1	3		7	114
I	E6016	1·45	½		1	2	1	28
J	E6016	4·39	2*		½	9*	7	202*
K	E6016	4·21	1			2	1	85
L	E6016	5·87	½			2	1	26
M	E6016	4·18	½			2	2	48
M	E6016	3·98	½			2	2	48
N	E8016	11·4	½			2	1	45
0	E4510	0					10†	66

* Probably a defective electrode or batch-weld contaminated with clusters of particles associated with microcracking.
† Presumably iron oxide.

low pressure. This possibility has not been so far investigated.

It is worth noting that an electrode with a light dust coating (bare wire) gave a low cracking density (66 microcracks/in.) and, in this case, the cracks had a different appearance and were probably predominantly of a different type from the microcracks which are of main interest in the present work.

Hydrogen Content and Microcracking Density

The result of plotting the density of microcracking against hydrogen content is shown in Fig. 5. With two exceptions, the results appear to fall in a broad band as shown. This would indicate a slight trend to increasing cracking with increasing hydrogen content. Probably there is a threshold value for hydrogen content (5–10 cc/100 g when measured by the technique described), above which substantial microcracking is liable to occur.

Much interesting and useful data on hydrogen in steel and in weld metal is contained in the paper by Vaughan and de Morton.[14] However, their technique of introducing hydrogen by electrolysis involves the danger of excessive concentrations in the surface layers (perhaps in the order of 30–50 cc/100 g). Cracks produced by this means are different in appearance and probably different in nature from weld-metal microcracks.

It is not surprising that any factor tending to increase the general hydrogen content of the weld metal such as the deliberate incorporation of moisture in the electrode coating, or an increase of welding current,[13] for example, would increase the extent of microcracking. An increase in hydrogen content with increase of welding current was demonstrated by Winterton and Cottrell.[8]

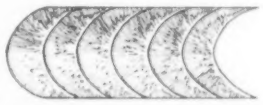
Effect of Inclusion Type and Distribution on Microcracking

The nonmetallic inclusions found in the weld deposits have been classified as follows:

Type A. This was very common and is illustrated in Fig. 6. It consists of a slate colored semitransparent matrix containing darker spheroids. This is probably rhodonite $(MnFe)O.SiO_2$ with glassy silica SiO_2 included. A previous paper[15] makes reference to the identification of inclusions by X-ray diffraction showing only rhodonite as common to a large number of different electrode types. Glassy silica would not be detected by X-ray diffraction. Examination in dark field caused extinction of the dark spots, indicating good surface reflection from the "dark" spot under oblique light. The idea that small transparent inclusions would appear black because of internal reflection has been discussed previously.[16] The suggested composition is in line with the fact that published data[15] for a typical range of weld deposits indicate that the ratio of silica to manganese (plus ferrous) oxide is about that required for rhodonite, often with excess silica.

Type B. This had a very similar form to Type A, but the matrix was pinkish and more translucent and the spots were larger, less numerous and not so dark by contrast with the matrix. Possibly this is a modified form of Type A containing titania, e.g., $(MnFe)O.Si(Ti)O_2$. It may be noted that $FeO.TiO_2$ has occasionally been identified in weld deposits by X-ray diffraction. Type B inclusions are more common in rutile-coated electrodes.

8a. Development of ripple markings by successive waves of weld metal



8b. Structure seen by macro-etching mid-horizontal section (i.e. cutting through lamellae) showing columnar growth

Type C. These were glassy silica inclusions, quite transparent showing a number of rings and reflections from the top and bottom surfaces. These inclusions have been illustrated previously.[16] The silica is glassy because the transformations are sluggish. Because it is in this form, it cannot be detected by X-ray diffraction.

Type D. Irregular opaque masses, believed to be calcium fluoride (CaF_2), are found only in weld metal from the low-hydrogen basic-coated electrodes. This has been identified on weld metal by X-ray diffraction.

Type E. These were very fine particles probably of miscellaneous types, but too small to identify. This class probably includes the manganese sulphide inclusions, but undoubtedly other types are represented, i.e., probably, but not certainly, the types listed above.

An attempt has been made in Table 3 to indicate the amount of each of the above types of nonmetallic inclusions present in a given weld deposit by allotting an index from 1 to 10 for each type of inclusion. Though arbitrary, this will give some idea of relative quantities for the electrodes studied.

The occurrence of microcracking is usually directly associated with nonmetallic inclusions. Fig. 7 shows a typical view of a microcrack passing through an inclusion. This inclusion is of Type A and, in fact, inclusions of Types A and B appear to be most often associated with the microcracking. If the inclusions are not immediately apparent, they can be usually detected at

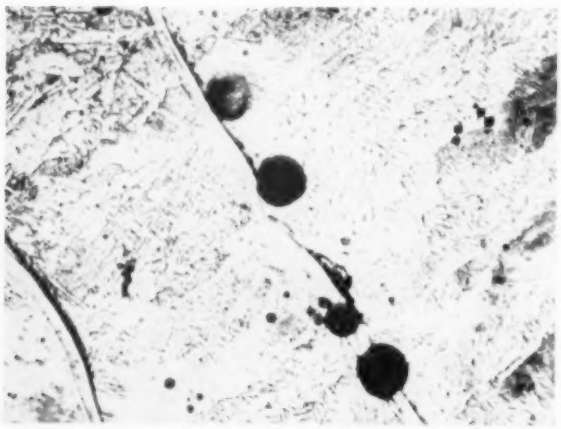


Fig. 9 Segregation at ripple markings. Etched nital. X 500 (Reduced by 40% upon reproduction)

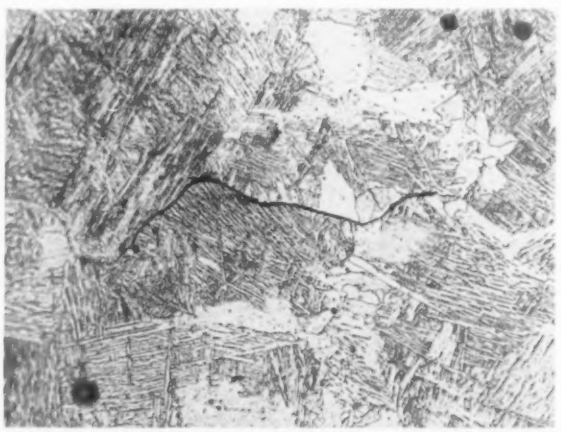


Fig. 10 Hot crack with transcrystalline extensions. Etched nital. X 500

higher magnification (about × 1000). It is possible that microcracking occurring between the columnar grains may be initiated by hot cracks rather than inclusions, as explained in more detail later.

It might be thought that the nonmetallic inclusions in weld metal are randomly oriented. This is not the case, because of a type of segregation peculiar to arc welding. Figure 8*a* shows, in side elevation and schematically, the development of ripple markings due to successive deposition of layers of weld metal. In a horizontal section of the weld, such as used in the present tests, these markings are delineated by the columnar growth. These zones are not normally observed at high magnification, but the limits may be outlined by scratching with a needle, using a low-power binocular microscope. Using this technique, it can be shown that the larger inclusions tend to lie along the scratch marks (Fig. 9). They have apparently been swept to the edges of the ripple markings by the strong columnar growth. This gross segregation means that the surfaces between the weld layers will be surfaces of weakness, because of the presence of large inclusions and associated microcracking. The smaller inclusions tend to be trapped between the growing columnar grains. This may also be seen in Fig. 9.

Inclusions, Hydrogen and Microcracking

Hydrogen cannot embrittle steel or steel weld metal to any marked degree at normal temperatures while it is freely diffusing through the lattice. Embrittlement is due to the accumulation of hydrogen under pressure in pre-existent cracks or cavities in the material, and the phenomenon of microcracking is due to the extension of these flaws under the action of the growing residual stresses.

To what extent the same thing can happen with flaws of atomic order such as vacancies, singly or in groups, grain boundaries, etc., is not known. Such effects, if any, will be masked by the macroscopic effects associated with cracks and cavities. Similarly, we are not concerned here with the relative merits of the original pressure-cavity theory of Zappfe and Sims,[17] and the adsorbed-hydrogen, surface-energy, theory of Petch.[18]

In mild-steel weld metal, there are four main kinds of pre-existent flaws to be considered: (*a*) cavities or misfit at the boundaries of inclusions, (*b*) cracks within inclusions, (*c*) hot cracks at the intersection of grain boundaries with inclusions, and (*d*) incipient hot cracks at grain boundaries.

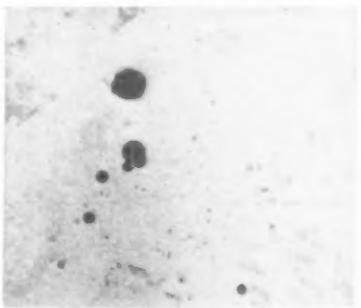
The thermal coefficient of contraction of silica and silicates is much less than that of iron. Consequently, on cooling, the inclusion itself will be in compression. The adjacent metal will be subjected to a hoop tension combined with radial compression.

If any of the pre-existent flaws (*a*), (*b*) or (*c*) is present, then hydrogen under pressure in the cavity will augment the existing stress system and may result in radial cracking. Star cracking or cracking in several radial directions is in fact frequently observed. Superimposed residual stress causes microcracking.

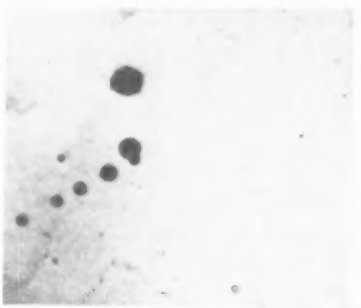
Another type of weld defect is probably directly related to the microcrack, i.e., haloes.

The production of haloes follows from the application of an external stress sufficient to cause a further opening of the fissures assisted by the internal pressure of hydrogen. Radial brittle failure occurs giving the characteristic halo, or fish-eye, appearance, after the specimen has undergone sufficient general deformation.

a—Initiation of hydrogen bubble at periphery of type A inclusion



b—Second stage of hydrogen evolution from inclusion (3 seconds later)



c—Third stage of evolution of hydrogen from inclusion (5 seconds later)

Fig. 11 Sequence showing evolution of hydrogen from periphery of inclusion. Photographed through thin layer of glycerine. Bubbles of hydrogen are formed in glycerine X 100 (reduced by 1/3 upon reproduction)

Figure 10 shows an intercrystalline crack presumably caused by hot cracking. It is interesting to note that the extremities of this crack are transcrystalline, suggesting that the crack has been extended at low temperatures in the manner discussed.

The following test was interesting in connection with these ideas. A freshly-made and quenched weld was deposited using electrode H (see Tables 1 and 3) and quickly prepared for microscopical examination. When this was immersed in glycerine, bubbles of hydrogen began to escape from the surface of the weld metal. On examination under the microscope, it was seen that small bubbles formed and escaped only at particular locations, usually from the periphery of inclusions. This is shown in Fig. 11*a*, *b* and *c*. Examination of the dry specimens at high magnification showed that microcracks were present at the points of escape. This serves to demonstrate that hydrogen will only escape, recombine to the molecular state, and coalesce at the available cavities and spaces.

As long as hydrogen (in atomic or ionic form) is diffusing into a cavity, the system is practically irreversible, and an indefinitely-high pressure can be built up.* At any given temperature, the reaction $H_2 \overset{Fe}{\rightleftharpoons} H + H$ will proceed to a limited extent and cause loss of pressure. At room temperature, this dissociation is, however, indefinitely slow, and appreciable dissociation occurs only at temperatures approaching 550° C.

The inclusions Type A and Type B seem to be particularly prone to initiate microcracking. It has been noticed that the dark spots (SiO_2) have often gravitated to the periphery of the ground mass (rhodonite) and even project a little. The irregular surface of these inclusions is probably unevenly stressed, taking into account differential contraction of the different phases present.

The relationship between the number of pre-existent flaws and the hydrogen content is extremely important. For a given number of flaws there is a minimum hydrogen content to cause microcracking. With less than this level, no cracking or reduced cracking will be obtained. Above the minimum level, the microcracks will increase in length but not in number.

The weld metal from low-hydrogen basic-coated electrodes has both low hydrogen and a low inclusion count.

* Approximate calculations show that ample hydrogen is present to account for extremely-high pressures in the available cavities.[19]

Presumably the ratio of hydrogen to inclusions is such that few microcracks are normally encountered. This does seem to carry the implication of some danger in that a slight change in this ratio would lead to the formation of a few long cracks rather than many short cracks.

On the other hand, with other types of coated electrodes, there are many inclusions together with ample hydrogen. The ratio of hydrogen to inclusions again determines the extent of microcracking.

It is now possible to explain the low level of microcracking associated with the weld metal from electrode H (Fig. 5). Although the hydrogen content is rather high, the inclusion count is exceptionally high, so that only at certain locations is the pressure great enough to develop microcracks.

Conclusions

1. The phenomenon of microcracking in mild-steel weld metal, previously reported in work done in the U.S. and in several European countries, has been observed in several electrodes available in Canada.

2. Microcracking was obtained even with low-hydrogen basic-coated electrodes with only moderate cooling rates, though to a much less degree than with other types.

3. An aggressive etchant is required to reveal microcracks in mechanically polished specimens.

4. There is normally a slight trend for increasing microcracking near the beginning and end of a bead. This is a cooling-rate effect.

5. A change in plate temperature from 20° C down to 0° C had a pronounced effect, increasing the extent of microcracking. This is due to changes in the low-temperature cooling rates controlling the amount of hydrogen retained.

6. No correlation was obtained between weld hardness and the density of microcracking.

7. An explanation is put forward for the incidence of microcracking in terms of the accumulation of hydrogen in preexistent flaws with superimposed residual stresses. The flaws in which the hydrogen accumulates are (*a*) cavities or misfit at the boundaries of inclusions, (*b*) cracks within inclusions, (*c*) hot cracks at the intersections of grain boundaries with inclusions, and (*d*) incipient hot cracks at grain boundaries.

8. Nonmetallic inclusions found in mild-steel weld metal have been classified into five general types. Any of these can be associated with microcracks, but most important seem to be rhodonite inclusions containing free silica.

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THE EVOLUTION OF STEEL BRIDGES IN BELGIUM DURING THE LAST 25 YEARS

BY G. WILLEMS AND R. FOUGNIES

The authors are Director-General and Inspector-General of bridges in Belgium and provide a thorough survey of all bridge construction in Belgium during the past 25 years. There are 33 photographs of Belgian bridges. The authors in their conclusion make four points concerning the evolution of stationary and movable bridges in Belgium.

1. Bridges, both welded and riveted, have been lightened continuously, thanks to new methods of design.

2. After a number of accidents which set back welding, there has been a progressive return to welding using connections particularly adapted to the process and steel adequate to the severity of service. For example, the Hasselt bridge was replaced by a completely riveted Vierendeel bridge, which was destroyed in 1944. Its replacement was partly welded, partly riveted. The trend is to shop-welded bridges with riveted field connections.

3. Research into esthetics is a part of every bridge project and welding is a great aid to smooth appearance.

4. Recent large bridges are utilizing increasing quantities of low-alloy, high-yield strength Steel 52, both in riveted and welded designs. Its use constitutes an innovation in bridge construction.

Abstract by **Gerard E. Claussen** of "L' évolution des ponts métalliques en Belgique au cours des 25 dernières années," by G. Willems and R. Fougnies, published in *Acier Stahl Steel*, **22**, 243–256 (June 1957).

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HIGH-TEMPERATURE BRAZING OF ALUMINUM BRONZE TO INCONEL

Investigation set up to determine the possibility of brazing aluminum bronze without flux and, alternatively, to develop a satisfactory flux sufficiently soluble to be readily removed

BY DONALD CAPLAN AND ERNEST F. NIPPES

SYNOPSIS. The impracticability of avoiding the presence of an alumina film in the brazing of aluminum bronze is demonstrated by an examination of the thermodynamics of oxidation. Experiments show that Cu-5% Al can be brazed to Inconel with nickel-base filler metal in high-purity hydrogen in spite of the oxide film, but only if precautions are taken to keep the oxide film thickness to a minimum. This is feasible with laboratory specimens but not in practice. Experiments using tube-and-fin specimens are devised to simulate the conditions of commercial brazing practice and thus to investigate a variety of possible fluxes.

Fluxes based on borates are effective in overcoming the alumina film but, because of limited solubility of their residues, increase the danger of corrosion failure in service. Suitable fluxes based on mixed chlorides having more soluble residues are developed. A preferred mixture is 5 parts NaCl, 2 parts LiCl and 1 part CuCl.

The mechanism of fluxing with halide fluxes is considered to depend on undermining of the oxide film through the operation of the electrochemical cell Al_2O_3/flux/bronze. Dissolving the alumina film by formation of complex oxides of the form $LiAlO_2$ either contributes to the undermining or is an alternative mechanism.

Introduction

An attractive combination for a heat exchanger to operate in air at temperatures as high as 1500° F is one of aluminum bronze fins joined to Inconel tubes. Aluminum bronze approaches the ideal as a fin material since it has both the high thermal conductivity of copper and excellent high-temperature oxidation resistance derived from an aluminum-oxide barrier film which forms on its surface. Inconel as the tube material is satisfactory as to high-temperature strength, oxidation resistance and corrosion by liquid metal heat exchange fluids. A preferred method of fabrication is by brazing, using one of the recently developed nickel-chromium-base high-temperature brazing alloys.[1-5]

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The problem then becomes one of effecting a satisfactory joint. The same Al_2O_3 film that gives the bronze its oxidation resistance interferes with the wetting of the bronze by a brazing alloy. Whereas Inconel or the stainless steels are readily brazed in a dry hydrogen atmosphere, this has not proved possible with aluminum bronze. Use of a suitable flux can be expected to promote brazing. However, the heat exchanger is a compact assembly comprising hundreds of inaccessible joints which makes flux removal a major problem. Flux residues are an invitation to corrosion failures in service.[6] A further complication is that the aluminum bronze has a solidus temperature uncomfortably close to the flow temperature of the filler metals.

The purpose of the investigation described in this paper was to determine how it might be possible to braze aluminum bronze without flux, and, alternatively, to develop a satisfactory flux soluble enough to be readily removed and so avoid the corrosion hazard. Evaluation was based on visual and metallographic examination of two types of laboratory specimens. Brazing in hydrogen is discussed in terms of the thermodynamics of oxidation of aluminum and chromium. A fluxing mechanism is proposed on the basis of the flux as the electrolyte of an electrochemical cell and of complex oxide formation.

Thermodynamics

It is instructive to consider the thermodynamics of the pertinent oxidation reactions. Despite the fact that thermodynamics demonstrates not what necessarily will occur but only what has a possibility of occurring, valuable information in advance of experimentation may be obtained regarding, e.g., what are the requirements for an atmosphere to be nonoxidizing.

Oxide Film on Aluminum Bronze

Consider first the aluminum bronze. What must be the purity of the atmosphere in order to dissociate the Al_2O_3 film that forms on the bronze? Assuming a test temperature of 1880° F (1300° K) the necessary thermodynamic data are conveniently obtained from Coughlin's recent bulletin.[7]

The equation for the oxidation reaction and its standard free energy change are written

$$^4/_3Al + O_2 = {}^2/_3Al_2O_3;\ \Delta F^\circ_{1300} = -200{,}600 \text{ cal}^7 \quad (1)$$

The equilibrium constant is given by

$$K = \frac{(a_{Al_2O_3})^{2/3}}{(a_{Al})^{4/3} a_{O_2}} = \frac{1}{P_{O_2}} \quad (2)$$

Now P_{O_2}, the partial pressure of oxygen in equilibrium with Al_2O_3 at 1880° F, may be calculated by substituting the above free-energy change in the general relation

$$\begin{aligned} \Delta F^\circ_T &= -RT \ln K \\ -200{,}600 &= -1.987 \times 1300 \times 2.303 \log 1/P_{O_2} \\ \therefore P_{O_2} &= 1.5 \times 10^{-34} \text{ atm} \end{aligned} \quad (3)$$

That is, the dissociation pressure of Al_2O_3 at 1880° F is about 10^{-34} atmospheres. On the basis that a cubic foot of gas at one atmosphere pressure contains 10^{23} molecules, an oxygen partial pressure of 10^{-34} atm represents one molecule of oxygen per cubic mile! This is fanciful but does demonstrate the practical impossibility of dissociating the Al_2O_3 film in vacuum or inert gas at any reasonable temperature no matter how such atmospheres might be gettered.

The situation is much improved if one substitutes a hydrogen atmosphere where the water reaction acts to decrease the effective P_{O_2}. From the standard free energy change for the water reaction at 1880° F, the ratio of H_2O to H_2 equivalent to a P_{O_2} of 10^{-34} atm can be calculated.

$$H_2 + {}^1/_2O_2 = H_2O;\ \Delta F^\circ_{1300} = -42{,}000 \text{ cal}^7 \quad (4)$$

The equilibrium constant for this reaction is

$$K_{H_2O} = \frac{P_{H_2O}}{P_{H_2}} \frac{1}{(P_{O_2})^{1/2}} \quad (5)$$

The ratio P_{H_2O}/P_{H_2} is obtained by substituting the value of K_{H_2O} at 1880° F determined from eqs 3 and 4, and the P_{O_2} just calculated for the dissociation pressure of Al_2O_3. The resulting value is $P_{H_2O}/P_{H_2} = 1.5 \times 10^{-10}$.

That is, in hydrogen at atmospheric pressure, the P_{H_2O} must be less than 10^{-10} atm to prevent oxidation of the aluminum or to dissociate Al_2O_3. The corresponding dew point is −180° F.[8]

Although such partial pressures of H_2O are theoretically obtainable with a cold trap [e.g., the vapor pressure of ice at liquid nitrogen temperature (−320° F) is about 10^{-26} atm] they are not obtainable in practice. Such an atmosphere is extremely prone to contamination by evolution of gas from metal when heated, dissociation of ceramics containing silicates, desorption of gases from the walls of the apparatus, and inability of the purification train to remove O_2, CO, CO_2 and H_2O to a sufficiently low degree. In the present work the source of contamination most difficult to circumvent was the dissociation of the less stable oxide Cr_2O_3 always initially present on the Inconel.

In view of these facts it would appear that the prospect of brazing in hydrogen is not promising. Nevertheless, under experimental conditions suitably controlled to minimize the thickness of the Al_2O_3 film, some limited brazing in hydrogen did prove possible, as will be seen.

Oxide Film on Inconel

As partial substantiation of the applicability of the foregoing type of calculation it can be shown by a similar calculation that Inconel should be readily brazed in hydrogen, as is observed.

The oxide film that forms on Inconel can be either Cr_2O_3 or the spinel-type oxide $NiO \cdot Cr_2O_3$. The spinel is favored thermodynamically but Cr_2O_3 actually forms under many experimental conditions. The calculations are conveniently based on Cr_2O_3.

$$^4/_3Cr + O_2 = {}^2/_3Cr_2O_3: \quad \Delta F°_{1300} = -127{,}200 \text{ cal}^{17} \quad (6)$$

Substituting in eq 3 as before

$$-127{,}200 = -1.987 \times 1300 \times 2.303 \log 1/P_{O_2}$$
$$\therefore P_{O_2} = 4 \times 10^{-22} \text{ atm}$$

which once again is a very small dissociation pressure. However, in this case, when the use of a hydrogen atmosphere is considered, the corresponding ratio P_{H_2O}/P_{H_2} determined as before through eq 4 is $P_{H_2O}/P_{H_2} = 2.2 \times 10^{-4}$, so that in hydrogen, at atmospheric pressure and 1880° F, the moisture partial pressure may be as high as 2.2×10^{-4} atm (0.17 mm) before an oxide layer becomes stable. This is equivalent to a dew point of −31° F which is consistent with the observed fact that high-temperature brazing of stainless steels and of alloys of the Inconel type does indeed take place in commercially dry hydrogen (dew point −60° F).

Thus, the calculations indicate that although Inconel will be brazable in dry hydrogen at 1880° F, aluminum bronze will be so only with difficulty, if at all. The assistance of a flux will probably be required.

It should be noted that a further significance of the relatively high dissociation pressure of Cr_2O_3 is that during heating of the bronze and Inconel assembly, the surface film on the Inconel will dissociate, contaminate the hydrogen atmosphere locally, and so promote oxidation of the bronze.

Experimental

Materials and Specimens

Two specimen types were used for the brazing experiments—a simple tee and a tube-and-fin. For the tee specimens, $^9/_{16}$- × 3-in. panels cut from 0.031-in. Inconel and 0.016-in. Cu – 5% Al sheet were wired together so that the bronze panel formed the bar of the tee and the Inconel, the upright (Fig. 1). A second Inconel panel used to back up the bronze for greater rigidity proved a convenient place to attach a thermocouple. A stirrup of thin Inconel foil was slipped over the Inconel panel at the center to act as a retainer for the filler-metal powder.

Tube-and-fin specimens (Fig. 2) were prepared from $1^1/_2$-in. lengths of $^3/_{16}$-in. OD Inconel tubing, and fins of Cu – 5% Al 0.016-in. sheet with $^3/_{16}$-in. diam punched holes.

The materials before assembly were degreased, pickled, rinsed, dried and stored in a desiccator. Pickel for the Inconel was $HF\text{-}HNO_3$ and for the bronze, hot NaOH solution followed by a short dip in dilute HCl.

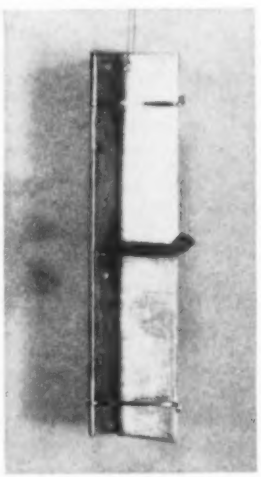


Fig. 1 Tee specimen, with central stirrup to retain powdered filler metal

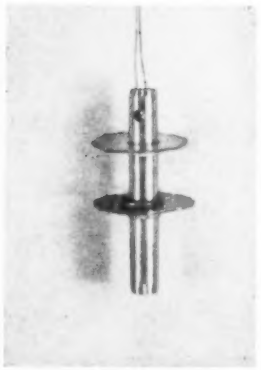


Fig. 2 Tube-and-fin specimen with filler metal ring at bottom joint

The brazing alloy of nominal composition Ni – 8Cr – 4B – 4Si – 3Fe was obtained from its manufacturer in powder form. No significant differences were observed in tests using a chromium-free alloy Ni – 4B – 5Si – 2Fe. The powdered filler metal was either cemented in place with a dilute solution of plastic in organic solvent or held in the pocket formed by the stirrup (Fig. 1). Preformed $^1/_4$-in. sintered rings of braze metal were used for the tube-and-fin specimens. Figure 2 shows such a ring placed only at the lower joint.

Apparatus

Most tests were carried out in a vertical tube furnace (Fig. 3). The temperature was held at 1880° F by a commercial controller. The mullite furnace tube of $1^1/_8$-in. ID was fitted top and bottom with brass fixtures. Vacuum-tight ceramic-to-brass seals were made with de Khotinsky cement. The specimen was attached at the bottom of the furnace to a Nichrome suspension wire hanging from a soft iron susceptor and raised to the hot zone by sliding the susceptor inside a long glass tube by an external magnet. Brazing of the specimen was observed through a sight glass in the upper brass head.

The gas train removed oxygen, nitrogen and moisture from electrolytic hydrogen supplied from the usual cylinder. (The Cu_2O furnace and Ascarite tower in Fig. 3 were used to purify helium in a series of experiments not reported here.) Final purification was by calcium chips (converted in place to CaH_2) at 1200° F. Only glass, metal and ceramic were used to minimize the risk of air leaking in. The apparatus was evacuated for leak-testing and removal of gaseous impurities from dead-ends and desiccants. Contamination of the specimen by gaseous dissociation products of the mullite tube was minimized by a rapid hydrogen flow rate; further, the ceramic dissociates only when hot and was not hot upstream from the specimen.

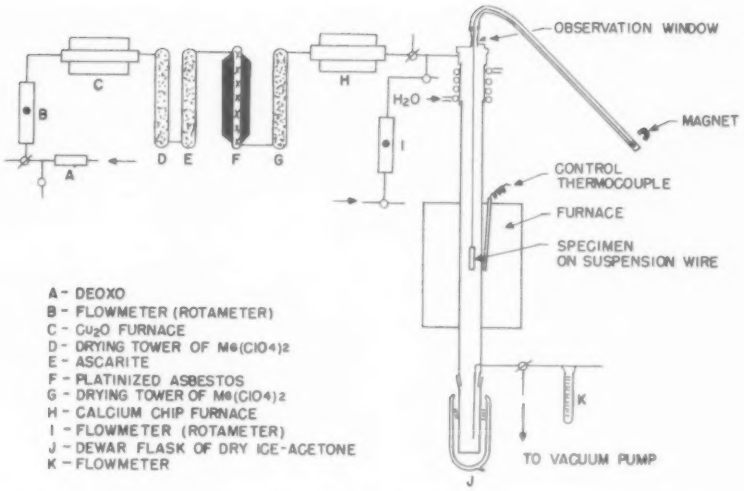


Fig. 3 Schematic diagram of vertical tube furnace

Some experiments were carried out in a horizontal tube furnace of similar design. For brevity, details are not included.

Procedure

Four test procedures were used in the brazing experiments.

Test A: Tee Specimen. The specimen was hung on the Nichrome wire, sealed into the apparatus, and raised to the hot zone. Flux, when used, was mixed and ground in a mortar and pestle, wet with acetone and applied to the joint as a slurry. In such cases the specimen was held for a few minutes in a warm zone toward the bottom of the furnace to dry the flux. A hydrogen flow of 500 ml/min was used corresponding to a linear flow of 0.5 ips at room temperature and 2.2 ips at 1880° F. The flow temperature was reached in about two minutes. The specimen was lowered to the cooling zone after six minutes and subsequently removed. Evaluation was by examination of metallographic sections and by visual examination after peeling the joint apart with pliers.

Test B: Tube-and-Fin Specimen. The procedure here was very similar to that of Test A except that a 3-min test time was used. The specimen was less massive and reached brazing temperature in about 1¼ min. It was not necessary to provide a dam for the filler metal since this was applied as a preformed ring.

Test C: Tube-and-Fin Specimen with High-Temperature Preheat. This test was designed to simulate the conditions of the actual brazing operation where the larger size of the heat exchanger results in a much longer time to reach brazing temperature.

The tube-and-fin specimen with a ring of filler metal on the lower joint only, as in Fig. 2, was raised to brazing temperature as usual but held at temperature for ten rather than three minutes to permit the oxide layer on the upper bronze fin to thicken. After cooling, a braze-metal ring was set at the upper joint, flux applied if desired, and the specimen raised to temperature for 3 min to braze the upper joint. The lower joint always brazed well and could be used for comparison with the upper.

Test D: Tube-and-Fin Specimen with High-Temperature Preheat Wrapped in Inconel Foil. The purpose of this test was to simulate not only the slower heating rate of the massive heat exchanger but the more severely oxidizing conditions in its inner recesses where the dissociation of the Cr_2O_3 film on the Inconel tubes increases the oxygen partial pressure. The complexity of the assembly prevents this locally contaminated atmosphere from being readily swept out by the flow of hydrogen.

As in Test C, a tube-and-fin specimen with braze metal on only the lower joint was used. This was wrapped in 0.002-in. Inconel foil and sealed into the furnace tube. The tube was evacuated to remove air trapped inside the wrapping. Hydrogen was admitted, flowed at 500 ml/min and the specimen raised and held at temperature for 10 min during which time the oxygen liberated from the oxide coating on the Inconel foil thickened the oxide layer on the upper bronze fin. After cooling, filler metal was set at the upper joint with flux if desired, the specimen rewrapped in Inconel foil, the evacuation repeated, hydrogen flowed and the specimen raised for the 3-min brazing period.

In all the tube-and-fin experiments the extent of penetration of filler metal into the crevice between the Inconel tube and the bronze fin was evaluated from metallographic sections.

Brazing in Hydrogen Without Flux

All four tests just described were used for this series. In addition, modifications were made to obtain further information. The effect of the absence of an Al_2O_3 film was observed by brazing a tee specimen in which a pure copper panel was substituted for the bronze. In case the decomposition products of the acrylic resin normally used to affix the braze-metal powder could interfere with wetting, hydrocarbon resins containing no oxygen in their molecules were tried; polyvinyl chloride and chlorinated rubber were tested to determine if the small amount of halogen liberated on thermal decomposition might assist brazing.

Brazing in Hydrogen with Flux

Most of the 97 brazing runs were directed to flux development. The primary object was an effective flux, preferably fluoride-free, having a readily soluble residue. Fluorides were known to promote brazing[9-11] but have the disadvantage of lower solubility and of contributing to high-temperature corrosion.

Types C and D experiments were ideal for evaluating fluxes. Application of flux at the upper joint demonstrated how effective was the fluxing action on the alumina film formed during the first part of these tests. Tee specimens were more suitable for comparing the flow of the better fluxes.

A variety of agents was tested as possible fluxes in preliminary experiments. Most were unsuccessful. These are listed briefly in the results section. The more effective fell into two groups, based either on borates or mixed halides.

Potassium pentaborate and four commercial borate-base fluxes were tested with tee specimens. Strong joints with good flow were obtained but the limited solubility of the flux residues motivated the investigation of more soluble bases.

Such fluxes were predominately mixed chlorides. A series of runs was carried out in which various "activators" were added to a mixture of 5 LiCl, 4 KCl and 1 NaCl. This base had the disadvantage of being too volatile to serve as a bath in flux dip brazing. Lower volatility was attempted by using alkaline earth chlorides and by decreasing the proportion of the more volatile constituents. Details of the flux formulations are in Tables 2 and 3 of the results section.

Results

The thickness of the oxide film as affected by the time to reach brazing temperature and the oxidizing potential of the atmosphere markedly influenced the brazing results. The partial compilation in Table 1 helps make this clear. Each result is a summary of a number of separate tests.

Test 3 of Table 1 shows that if a

Table 1—Brazing in Hydrogen Without Flux

No.	Specimen type	Test type	Result
1	Tee	A	Poor. Brazed only at isolated spots.
2	Tee (Cu panel)	A	Good.
3	Tube and fin	B	Good. Flowed into crevice.
4	Tube and fin	C	Upper joint not brazed. Bronze not wet.
5	Tube and fin	D	Lower joint not brazed. Bronze not wet.

tube-and-fin specimen is brought rapidly to temperature in pure hydrogen, a high-quality joint is obtained. The excellent penetration into the joint crevice is seen in Fig. 4. That very limited flow takes place is apparent from Test 1 in which a tee specimen under similar conditions brazed only where the filler metal had been preplaced. Brazing did not occur, however, after preheating for 10 min in hydrogen (upper joint of Test 4) nor when the atmosphere was contaminated from the dissociation of the oxide film on the Inconel foil (Test 5). Figures 5, 8(*b*) and 10(*a*) show how the filler metal did not wet the bronze but ran up to form a collar around the Inconel tube; this is consistent with the thermodynamic prediction above that Cr_2O_3 will dissociate under these conditions.

Fig. 4 Section through tube-and-fin joint formed in hydrogen without flux

Note penetration into crevice. Unetched. X 33. (Reduced by 1/3 upon reproduction.)

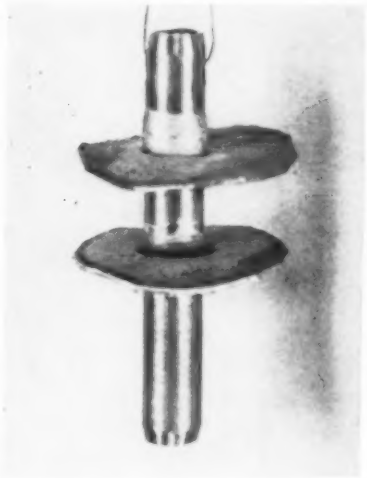


Fig. 5 Tube-and-fin specimen used in Type C experiment without flux

Good lower joint. Preheating of upper joint has prevented filler metal from wetting bronze fin

When copper was used in place of bronze and the alumina film thus avoided, a satisfactory joint resulted exhibiting good flow (Test 2). Attempts to achieve the same result through de-aluminizing a thin surface layer by preoxidizing and pickling off the oxide were unsuccessful.

Substituting a chlorinated hydrocarbon resin for the acrylic resin normally used to anchor the braze-metal powder brought no improvement. In fact, the results were worse—no joining even at isolated spots.

A considerable group of materials proved ineffective as fluxes. These were: chlorine as a gaseous mixture with hydrogen, iodine, sodium chloride alone and with sodium hydroxide or sodium cyanide, cuprous chloride, ammonium chloride, lithium chloride, zinc chloride, sodium hydroxide, cryolite, trisodium phosphate, and hydrides of titanium, zirconium or calcium.

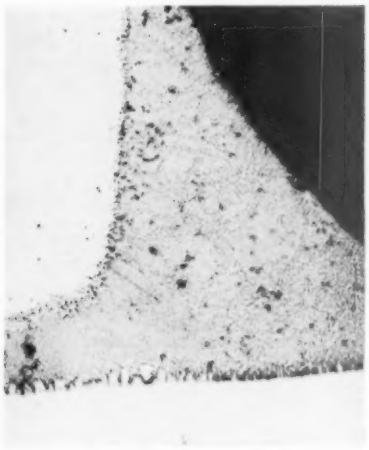


Fig. 6 Section through tee joint made with borate-base flux

Etched electrolytically in 5% H_2SO_4. X 100.

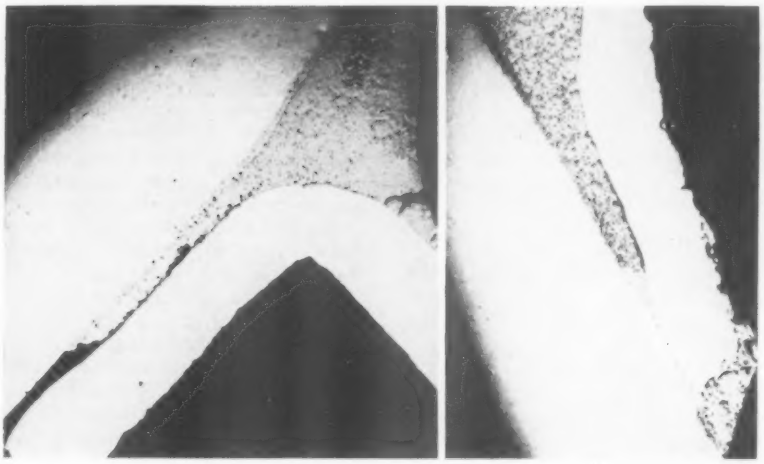
Borate-base fluxes either as potassium pentaborate or commercial brazing fluxes gave good joints over almost the full length of the tee specimens. Figure 6 is a section through a tee joint made with a borate flux. Vigorous brushing in hot water was necessary to remove the flux residues. Good joints also were obtained with commercial mixed halide fluxes despite their being designed for brazing aluminum, a lower-temperature process. It was observed that these fluxes contained water-insoluble components.

Table 2 is a summary of the experi-

Table 2—Brazing in Hydrogen with Chloride Fluxes

No.	Specimen type	Test type	Flux	Result
1	Tee	A	Base I*	Fair. Brazed half of length.
2	Tee	A	10 Base I, 2 AlF_3	Bad. No joining.
3	Tee	A	10 Base I, 2 $SrCl_2$	Bad. No joining.
4	Tee	A	10 Base I, 2 $FeCl_2$	Fair. Brazed 3/5 of length.
5	Tee	A	10 Base I, 1 $CrCl_3$	Fair. Brazed 1/2 of length.
6	Tee	A	10 Base I, 2 AgCl	Fair. Brazed full length. Bronze attacked.
7	Tee	A	10 Base I, 1 $CdCl_2$	Good.
8	Tee	A	4 KCl, 1 NaCl, 1 $CdCl_2$	Fair. Joint weak. Bronze not well wet.
9	Tube and fin	D	10 Base I, 2 $CdCl_2$	Good. But braze metal surface rough and spiny.
10	Tube and fin	D	10 Base I, 2 $CrCl_3$	Bad. No joining.
11	Tube and fin	D	10 Base I, 1 AgCl	Fair. Brazed all around. Bronze attacked.
12	Tube and fin	C	10 Base I, 1 TiH_2	Fair. Brazed 4/5 around.
13	Tube and fin	C	10 Base I, 2 $ZnCl_2$	Fair. Brazed 2/5 around. Poorly formed fillet.
14	Tube and fin	D	10 Base I, 2 $NiCl_2$	Good. Braze metal surface uneven.
15	Tube and fin	D	10 Base I, 2 CuCl	Good. Smooth fillet.

* Base I: 5 parts LiCl, 4 parts KCl, 1 part NaCl.



a b

Fig. 7 Sections through joints in Type C experiment

Unetched. X 50. (Reduced by 1/3 upon reproduction.) (a) Lower joint. No flux. (b) Upper joint. Flux of 5 LiCl, 4 KCl, 1 NaCl, 2 $CdCl_2$ used after 10 min preheat. Note penetration even better than in (a).

ments with mixed chloride fluxes. Most items represent two or more tests. For brevity, tee experiments usually are not listed if good results were obtained with the more exacting Type C or Type D experiments. In such cases good results were also obtained with the tee specimens. Similarly Type C experiments are omitted when Type D experiments gave good results.

The Table 2 illustrates that addition of zinc chloride, cadmium chloride, copper chloride or nickel chloride to the alkali chloride base led to satisfactory brazing; copper chloride gave the best results with smooth, well-formed fillets. Silver chloride was an effective additive but gave excessive "undercutting" or "alloying." Addition of titanium hydride was less effective, iron chloride or chromium chloride ineffective and aluminum fluoride or strontium chloride detrimental. Comparison of tests 7 and 8 shows that omission of lithium chloride leads to poorer results.

Figure 7 shows how use of alkali chloride plus cadmium-chloride flux in a Type C experiment led to better penetration even after the 10-min preheat (upper joint) than in the lower-joint experiment without flux where the Al_2O_3 film was of minimum thickness. (The contamination of the atmosphere which caused the incomplete penetration seen in Fig. 7(*a*) is due to an accumulation of salts in the furnace tube from previous flux experiments. These salts had to be washed out periodically.) Figure 8 shows the same good result under the even more adverse conditions of the

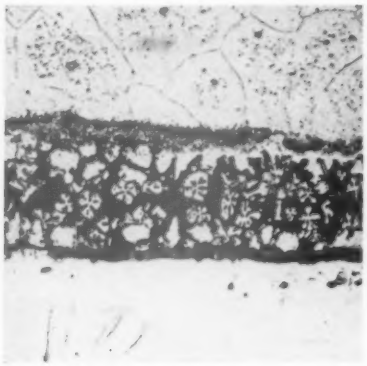
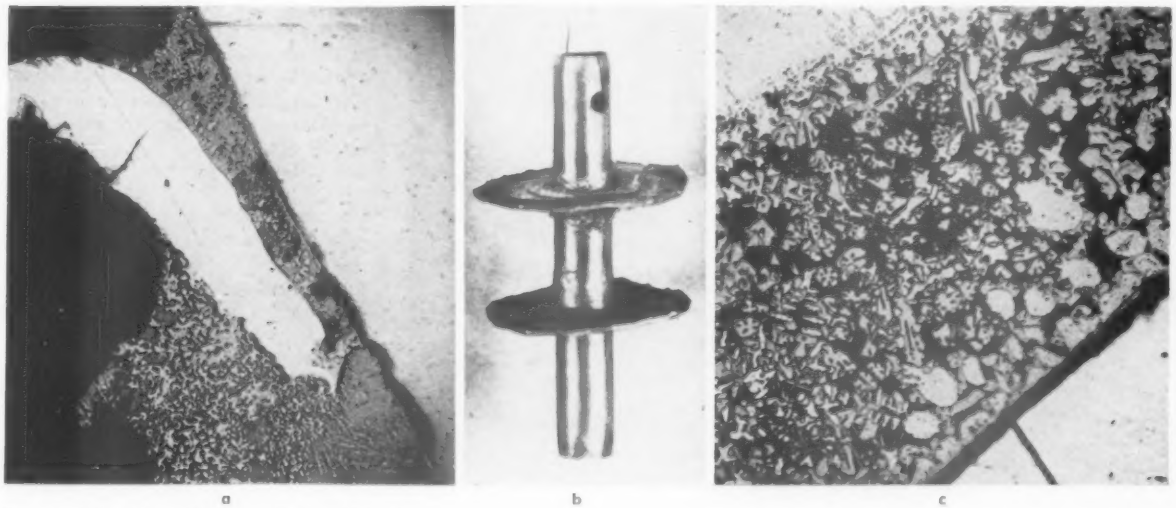


Fig. 9 Microstructure of filler metal within crevice of joint formed in Type D experiment using flux of 5 LiCl, 4 KCl, 1 NaCl and 2 $NiCl_2$

Etched electrolytically in 5% H_2SO_4. X 250. (Reduced by 1/3 upon reproduction.)

Type D experiment (Test 9). Figure 9 is of the filler metal in the crevice of a Type D experiment using a flux of alkali plus nickel chloride (Test 14).

Table 3 describes the modifications made to the flux formulas to achieve lower volatility. Table 4 shows some of the properties of the flux ingredients on which the flux design and these modifications were based. The first approach was to substitute the alkaline earth chlorides for the alkali chlorides because of the higher boiling points of the former. As shown in Table 3 (tests 1 to 7) this gave poor results except when both metal salt "activator" and fluoride were added to the salt base (Test 3). If possible this combination was to be avoided for reasons of low solubility and corrosivity in high-temperature service. The alkaline earth salts were, therefore, abandoned and the



a b c

Fig. 8 Joint formed in Type D experiment

Flux of 5 LiCl, 4 KCl, 1 NaCl, 2 $CdCl_2$ used for upper joint. (Reduced by 1/4 upon reproduction.) (a) Section through upper joint showing good penetration but rough surface. Unetched. X 50. (b) Photograph showing rough surface of upper joint and failure to braze of lower joint. (c) Microstructure of filler metal in crevice. Etched electrolytically in 5% H_2SO_4. X 250.

Table 3—Brazing in Hydrogen with Chloride Fluxes of Lower Volatility

No.	Specimen type	Test type	Flux	Result
1	Tee	A	3 $BaCl_2$, 1 NaF, 5 $CaCl_2$, 2 NaCl	Bad. No joining.
2	Tee	A	3 $BaCl_2$, 1 $ZnCl_2$, 5 $CaCl_2$, 2 NaCl	Poor. Brazed for $^3/_8$ in.
3	Tee	A	3 $BaCl_2$, 1 NaF, 5 $CaCl_2$, 1 $ZnCl_2$, 2 NaCl	Good.
4	Tee	A	9 $BaCl_2$, 1 $NiCl_2$, 1 LiCl	Bad. No joining.
5	Tee	A	8 $BaCl_2$, 1 $CdCl_2$, 1 LiCl, 1 NaCl	Fair. Brazed $^1/_2$ of length.
6	Tee	A	5 $BaCl_2$, 2 $CdCl_2$, 5 LiCl, 1 NaCl	Bad. No joining.
7	Tee	A	3 $BaCl_2$, 3 $SrCl_2$, 5 LiCl, 2 $CdCl_2$, 2 NaCl	Bad. No joining.
8	Tube and fin	D	5 NaCl, 1 CuCl, 2 LiCl	Good. Smooth fillet.

Table 4—Physical Properties of Flux Ingredients

Compound	Melting point, ° C	Boiling point, ° C	Solubility, g/100 g
LiCl	614	1382	45
NaCl	800	1465	36
KCl	770	1407	35
$MgCl_2$	714	1418	35
$CaCl_2$	782	>1600	60
$SrCl_2$	872	...	44
$BaCl_2$	960	1560	31
$ZnCl_2$	365	732	432
$CdCl_2$	568	967	140
CuCl	430	1490	0.006
AgCl	455	1564	0.001
$NiCl_2$	1030	...	64
LiF	870	1681	0.27
NaF	992	1704	4.2
BaF_2	1350	2220	0.17
ZnF_2	872	1500	Sl. sol.
NiF_2	...	...	0.02
CuF	908	...	Insol.

lower volatility achieved by omitting the lower-boiling potassium chloride and decreasing the proportion of lithium chloride. On grounds of volatility copper chloride is to be preferred to zinc chloride, cadmium chloride or nickel chloride and furthermore gave better joints. Figure 10 shows the high quality joint formed with a flux of 5 NaCl, 2 LiCl, 1 CuCl (Test 8 of Table 3). The smooth fillet at the upper joint can be seen in Fig. 10(*a*). Good results were obtained in both A and D type experiments.

Discussion

That aluminum bronze can be brazed to Inconel in dry hydrogen in spite of the unfavorable thermodynamics is apparent from the brazing experiments without fluxes. The prerequisites, however, are stringent. If the panels are first well cleaned of their oxide films, a high-purity hydrogen atmosphere maintained, and the specimen brought to temperature in as short a time as 2 min, the Al_2O_3 film on the bronze does not become thick enough to prevent joining. The extent of flow will still be very limited.

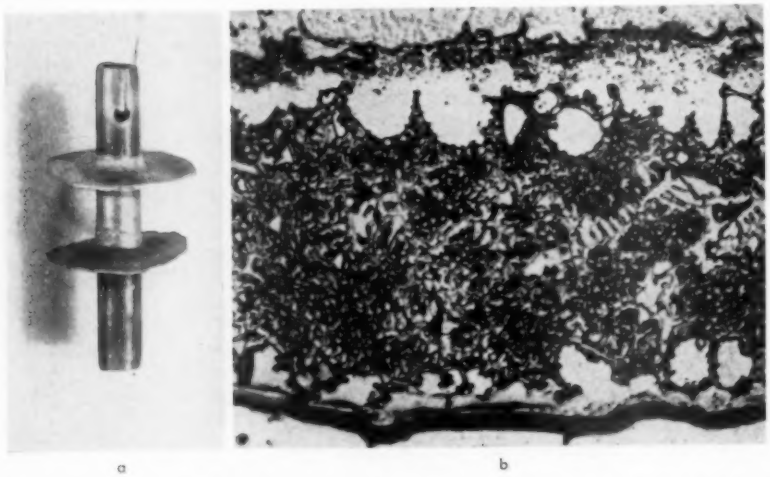
Unfortunately, these are not the conditions in the brazing of a heat exchanger: the large mass induces a slower heating rate; the complexity of the assembly combined with the dissociation of the oxide film on the Inconel tubes gives rise to a locally contaminated atmosphere.

The Type C and Type D experiments simulated these adverse conditions. They demonstrated that when conditions were such as to allow the alumina film to thicken, the bronze could not be wet. Accepting the fact then that the Al_2O_3 film cannot be prevented from forming and that it is not feasible to keep it thin enough to be harmless, it is necessary somehow to circumvent its presence. Use of a flux is one possibility.

Reluctance to using a flux stems from the anticipated difficulty of removing every trace of its residue and the consequent danger of a service failure through corrosion. Borate-base fluxes were found to give good joints. Unfortunately, borate residues are not readily soluble and would be practically impossible to remove from the interstices of the intricate assembly. Therefore, a more soluble flux is required.

A base of alkali chlorides including lithium proved satisfactory when "activated" with an addition of zinc, cadmium, nickel or copper chloride. Since the brazing is carried out in hydrogen, the amount of oxide formed is small, and hence the quantity of so-called glass (reference 1, page 39) in the flux residues is a minimum. The residues should thus be readily soluble. Of the "activators," copper chloride was preferred in spite of its lower solubility (Table 4); besides giving the smoothest fillets, it does not, like cadmium or zinc, introduce a stranger element which could interfere with the development of the proper barrierlike characteristics of the Al_2O_3 or Cr_2O_3 films on which the high-temperature resistance depends. Presumably it would be readily removed, despite its lower solubility, since as a minor constituent it would be flushed out when the soluble chloride matrix dissolved.

A secondary aim was for the flux to be of low enough volatility to serve as a bath for flux dip brazing. Formulations based on the less volatile alkaline earths (Table 4) were unsuccessful without fluoride additions. The alkali chloride base was therefore adhered to but modified in the direction of lower volatility. The proportion of sodium chloride was increased, the potassium chloride omitted and the lithium chloride



a b

Fig. 10 Joint formed in Type D experiment using preferred flux 5 NaCl, 2 LiCl and 1 CuCl at upper joint

(a) Photograph showing the smooth fillet of the upper joint and failure to braze of lower joint. (b) Microstructure of filler metal in crevice. Etched electrolytically in 5% H_2SO_4. X 500. (Reduced by $^1/_4$ upon reproduction.)

decreased. The preferred composition thus became the mixture of 5 parts NaCl, 2 parts LiCl and 1 part CuCl.

Fluxing is not the only possibility for overcoming the alumina barrier film. Still to be investigated are the use of supersonic vibrations to disrupt the film, and the addition of lithium metal to the filler metal to form a self-fluxing braze. Bredzs and co-workers have demonstrated this self-fluxing action with copper and silver brazes.[12–14] A third procedure is to modify the surface as by plating so that an alumina film would not form during brazing (but would in service). Beryllium copper is copperplated for silver brazing. Preliminary experiments have not been encouraging. Still a fourth approach is to arrange the conditions in brazing the heat exchanger as similar to the laboratory tests as possible. This involves rapid circulation of highest-purity hydrogen directed into the interstices of the assembly, combined with auxiliary heating to reach brazing temperature rapidly, as by circulating a high-temperature liquid through the Inconel tubes. This fourth scheme appears the least promising.

Mechanism of Fluxing

The relation of the balance of surface free energies or interfacial tensions to the spreading of liquid metals, the filling of joints and the interference effects of surface films has been well developed.[15–18] However, publications dealing with fluxing present a more confused picture.[17–23] The chemistry of fused salts is difficult so that the role of flux in a system is not always clear and a comprehensive interpretation of fluxing has not yet evolved.

Having established that the Al_2O_3 film cannot be avoided even in pure hydrogen, there are three ways in which brazing could conceivably take place: the liquid metal might be persuaded to wet or bond to the oxide film; the film might be undermined by the flux and filler metal; or the film might be dissolved by the flux.

Wetting of Al_2O_3 by the nickel-base alloy is unlikely. On the model presented by Livey and Murray,[18] the large anion/cation ratio of Al_2O_3 gives it a highly negative surface. This strongly repels the negative electron cloud of the liquid metal, especially when the metal has as high an atomic number as nickel. The result is a high contact angle. Certain factors tend to counteract this unfavorable situation. Elemental lithium, for which the screening of the positive nucleus by the electrons is small, would more readily wet the oxide, as would the more electropositive element chromium.[24] Substitution of larger and therefore less polarizable cations such as cadmium, zinc, silver or copper in the surface layer of the Al_2O_3 would decrease the electronegativity of the surface and make it more readily wettable. A detailed consideration of these and other factors might be treated on the Livey and Murray model,[18] but the attempt will not be made since this mechanism is not believed important in the present system.

More probably, the function of the flux is to present an oxide-free surface to the liquid metal. Jordan and Milner[23] have advanced a reasonable explanation of the fluxing mechanism in the brazing of aluminum. It embodies the evidence of West[21] and Sully, Hardy and Heal,[22] as well as their own, that the oxide does not dissolve in the flux; their interpretation is that the oxide is undermined by electrochemical action between the oxide and metal.

To extend this theory to the present case, the cell involved has the Al_2O_3 film as cathode, the bronze as anode and the molten salt as electrolyte. The anodic process may be written $Al(Cu) \rightarrow Al^{+++} + 3e$ summarizing that the bronze dissolves in the flux but that the copper subsequently redeposits. This "de-aluminization" is similar to the mechanism for the removal of zinc from brass in the dezincification type of corrosion. The copper-colored surface generally observed on the bronze after brazing supports this view.

If the concentration of oxygen trapped in the flux is not too small, the cathodic process could be $O + 2e \rightarrow O^{=}$ as deduced by Jordan and Milner.[23] Oxygen and moisture are very difficult to remove from even molten salts,[25] so that the oxygen concentration could possibly be sufficient to act as cathodic depolarizer even though the tests are carried out in hydrogen.

Also operable as a cathodic process is the reduction of relatively noble cations as $Ni^{++} + 2e \rightarrow Ni$. This would appear to be the purpose of adding the "activators," CuCl, $NiCl_2$, AgCl, etc. Whether the more electronegative cations, zinc and cadmium, also act as depolarizers is not certain. They might function, rather, as "tinning" agents,[17,19] alloying with the surface layer of metal to depress the formation of further oxide and to promote wetting by lowering the melting point. The cathodically reduced cations also would contribute to surface alloying. The marked "undercutting" when AgCl was used in the flux is due to the formation of such a lower-melting copper-silver alloy; the bronze surface became silver-colored. Brazing tests in air with the alkali chloride flux and no "activator" were unsuccessful, indicating either the necessity of this surface alloying or that oxygen cannot act as a cathodic depolarizer. (Experiments in air with "activators" showed joining with some of the successful fluxes and not with others; the joint quality was poor. The braze metal became copper-colored, perhaps reflecting greater activity of the electrochemical cell.)

The third possibility for overcoming the problem of the alumina film—that of solution of the oxide—has been negated in the case of aluminum brazing.[21–23] However, in view of the fact that the bronze is brazed at a temperature 700° F higher than is aluminum, fluxing by solution of the barrier film must be reconsidered. At this higher temperature, the solution of Al_2O_3 would be promoted by the presence in the flux of the lithium salt, leading to a reaction of the type $Li_2O + Al_2O_3 \rightarrow 2LiAlO_2$. This, or the spinel-type oxide $LiAl_5O_8$, can be expected to have a melting point in the range 1500 to 1800° F[26] which on phase rule considerations is synonymous with being soluble in the flux at 1880° F. (In the cermet field complex oxide considerations of similar type have been receiving attention relative to the wetting of oxides and carbides by liquid metals.[27–29]) The beneficial effect of the lithium salt addition is the result of the strong tendency for lithium to formed mixed oxides.[12,20,26]

In the peeling mechanism, this same solution through complex oxide formation would contribute to the initial penetration of the oxide film. Penetration is a prerequisite to the establishment of the electrochemical cell. On the other hand the role of the "activators" in the solution mechanism could be further to lower the melting point of the mixed oxide by substitution. It is not unlikely then that the two mechanisms—peeling and solution—are interrelated. Experiments on solubility and viscosity of the alumina/fused salt systems, such as those of Sully, Hardy and Heal[22] but at higher temperature and with lithium salts, would help to evaluate which is more important.

Conclusions

1. When brazing aluminum bronze it is not feasible to avoid the presence of an alumina film even in dry hydrogen. It is possible to predict this from thermodynamics. That such a film interferes in brazing with nickel-base filler metal is demonstrated by laboratory tests devised to simulate commercial brazing practice.

2. In spite of the alumina film, nickel-base brazing of aluminum bronze to Inconel in hydrogen can be effected provided precautions are taken to minimize the film thickness. Necessary are a rapid heating rate and a rapid flow of high-purity hydrogen to sweep away oxygen from the dissociation of chromium oxide on the Inconel. Such precautions are possible with small laboratory specimens, but not in practice.

3. Fluxes based on borax are effective but are undesirable because of the limited solubility of the flux residues. They would, therefore, be difficult to

remove from an intricate heat exchanger, leading to possible corrosion failure in high-temperature service.

4. Chloride-based fluxes are effective and leave residues of adequate solubility. A preferred mixture is 5 parts NaCl, 2 parts LiCl and 1 part CuCl.

5. The mechanism of fluxing with chloride fluxes appears to depend on undermining of the oxide film through operation of the electrochemical cell Al_2O_3/flux/bronze. Formation of complex oxides of the form $LiAlO_2$, which are soluble in the molten salt, either contributes to the undermining or is an alternative mechanism.

Acknowledgments

The authors wish to express their appreciation to Oak Ridge National Laboratories for sponsoring the program of which this work was a part, and for permission to publish this report. In addition, they acknowledge the experimental efforts of John J. McCarthy and Joachim J. Hauser.

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THE EFFECT OF QUENCH AGING ON THE NOTCH SENSITIVITY OF STEEL

BY J. R. LOW, JR.

The effects of quench aging on the notched-bar impact behavior of a semi-killed ship-plate steel were reported in THE WELDING JOURNAL, Research Supplement in May 1952.* Briefly, it was found that the keyhole Charpy transition temperature increased continually for aging times at room temperature from one day to three years, with most of the increase occurring in the first year. The same material has now been tested after aging at room temperature for approximately nine years (3170 days) with the result shown in Fig. 1. Substantially no change was found in the Charpy curve as a result of the additional 6 yr aging, the most recent curve falling at about the same position as the 3-yr curve.

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* Low, J. R., Jr., "The Effect of Quench Aging on the Notch Sensitivity of Steel," WELDING JOURNAL, Research Suppl., **31** (5), 253-s–256-s (1952).

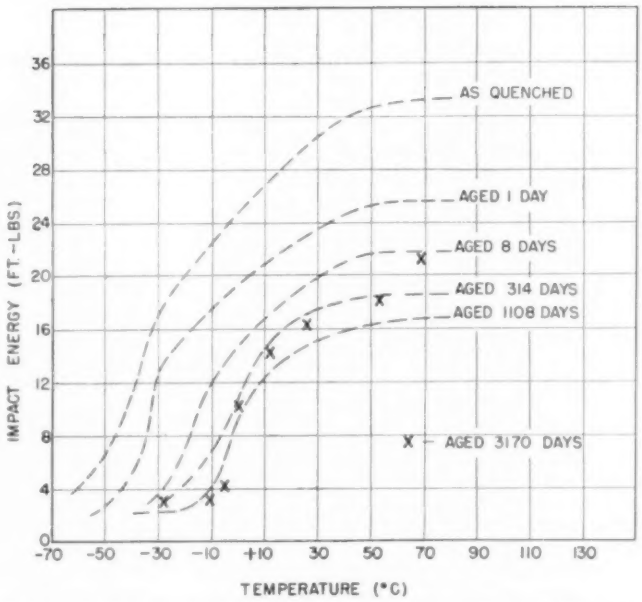

Fig. 1 Shift in the keyhole Charpy impact curve of a 0.17% carbon semikilled steel as a result of quench-aging. Specimen blanks quenched into water from 690° C and aged at 25° C for the times indicated.

THE EFFECT OF IMPACT ON BEAMS AND WELDED STRUCTURAL CONNECTIONS

Work at failure under impact found to exceed work at failure under static loading for similar beams and welded connections

BY PAUL J. BRENNAN AND HARRY A. B. WISEMAN

SUMMARY. Initial studies on light beams with welded connections were made under static and dynamic loading conditions. Strains were obtained on the top and bottom flanges near the welded connections. Time-strain curves were recorded for these locations both for impact that did not produce failure and for impact that did produce failure. The time of transmission of the stress wave was obtained between various locations on the beam and the shape of the time-strain curves at these locations compared.

Results show that for the theory used the computed work at failure under impact exceeded the work at failure under static loading for similar beams and welded connections. The ratio of dynamic to static work at failure was from 1.2 to 7.6. A linear relationship exists between the work required for failure in the weld and the area of the failure plane of the weld. A direct relationship also appears to exist between the work required for failure in the weld and the product of the curvature and moment of inertia.

Recommendations for a large scale test program to produce more positive and conclusive results are made.

Introduction

Object and Scope of Investigation

The increasing use of welded connections in structural building frames will cause these connections to resist diversified loadings. Two of these conditions are impact and blast. The determination of the ability of beams and welded connections to resist the portion of this energy that must be absorbed by them is the purpose of this investigation. Associated with this is a study of the shape of the impact strain-time curve for a beam that does not have weld failure and for a beam in which the welded connection fails. The time of transmission of the strain wave through the member and the variation of the shape of the strain-time curve at various locations were also obtained. These latter studies were considered important for evaluation of the theory of energy absorption.

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Presented at 1957 AWS National Spring Meeting, April 8–12, Philadelphia, Pa.

Four sizes of small beams were used for static and dynamic loadings with a minimum of six beams tested in each group. Four sizes of welded connections were studied. In all, 38 beams were tested to failure in the connection.

Description of Beams, Weld Metal and Connections

Lightweight beams, usually referred to as "junior beams" were used for all tests. These sizes included 12 x 3, 10 x $2^3/_4$, 8 x $2^1/_4$, and 6 x $1^7/_8$. The chemical and physical properties of these members as furnished by the manufacturer are given in Tables 1 and 2. Test coupons cut from the web in the direction of rolling and 90 deg from the direction of rolling were also tested.

Preliminary work was done with 8-ft beams supported and fixed at both ends and loaded at the third point. Work with these members showed that, because of the large amount of effort involved in fabricating and testing each member, the number of tests would be limited by continuing with this arrangement. Comparable results for the welded connections can be obtained by using cantilever members—the free end of the member corresponding somewhat to the point of zero curvature of continuous beams. This test program, therefore, used cantilever beams of such a length that buckling of the lower flange and web did not occur. This length was 42 inches from the centerline of the load to the face of the back plate, except for the cases noted.

Welding electrode was $^1/_8$-in. diam AWS-ASTM6013 for beams 10–1 through 10–8 and $^3/_{32}$-in. diam AWS-ASTM6013 for all other beam connections. The bottom-stiffened seat connections were cut from $^1/_2$ of an 8-in. wide flange section. Top plate connections were AISI 1020 steel sawed to size and shape.

All connections were rigid type with a stiffened lower seat and a rectangular or tapered top plate. These connections were designed to fail in the weld connecting the beam to the top plate since preliminary tests showed that for apparently equally strong top and bottom connections the top weld failed. Most connections were designed to fail before the beam reached the yield strength in the area adjacent to the weld. One set of beams yielded in the flanges adjacent to the connection before failure occurred in the weld. Details of all connections used are shown in Figs. 3 and 4.

Table 1—Chemical Composition of Steel Beams

Beam	*C*	*Mn*	*P*	*S*	*Cu*
6 x $1^7/_8$	0.21	0.42	0.020	0.022	0.26
8 x $2^1/_4$	0.21	0.50	0.017	0.017	0.24
10 x $2^3/_4$	0.21	0.45	0.020	0.020	0.22
12 x 3	0.21	0.44	0.018	0.020	0.24

Table 2—Physical Properties of Steel Beams

Beam	*Yield point, psi*	*Tensile strength, psi*	*Elongation in 8 in., %*
6 x $1^7/_8$	46,470	67,130	25.2
8 x $2^1/_4$	44,900	63,540	27.0
10 x $2^3/_4$	46,030	67,830	24.0
12 x 3	44,850	63,540	29.8

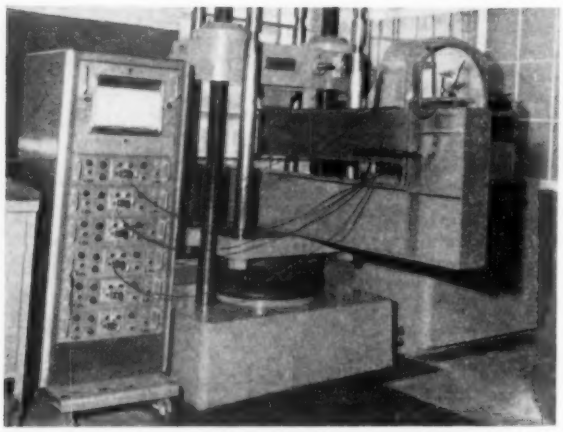


Fig. 1 Equipment and partial instrumentation for static tests

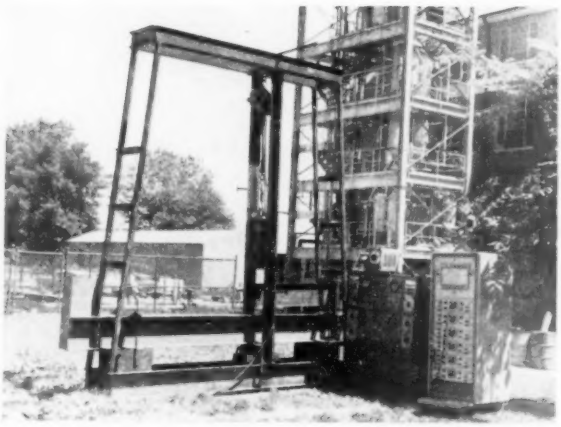


Fig. 2 Equipment and partial instrumentation for dynamic tests

To enable rapid changes of test specimens and to assure continuity of the test beam with the testing frame, all beam connections were welded to a $^3/_4$ x 6-in. plate. This back plate had a $^3/_4$ x 6-in. wide top plate welded to the back near the top. The top plate has a shear plate attached to permit hooking over a plate welded to the vertical column of the test frame. This gave a rigid connection between the test beam and the test frame. Clamps were used to keep the back plate from lifting vertically after impact. The same movable test frame was used for static loading in a 400,000-lb universal testing machine and for dynamic loading in an impact frame. This movable test frame is constructed of a 12WF27 with stiffened stub columns on each end. When this frame was used for dynamic testing it was supported at $9^1/_2$ in. from the end to which the test beam was attached. The other end was supported at eight feet from the first support. The horizontal member of the frame was clamped to the supports. This test frame is shown in Figs. 1 and 2.

Description of Equipment and Instrumentation

The impact-test equipment consists of two 14H108 rolled-steel sections 36 in. long embedded eighteen inches into a concrete base. This base is 3 ft wide, 10 ft long and 5 ft deep. The steel columns are spaced 8 ft on center. A frame for guiding the drop weight is attached to these columns. An electric hoist with a parachute quick-release mechanism lifts the weights.

Weights are available in sizes varying from 86 to 2000 lb. They can be lifted to about 5 ft. These weights have a T section attached to each side to fit the vertical angle guides. These guides were sufficiently clear of the T section to eliminate binding; however, they were well greased to decrease friction if the T section rubbed against the angle.

To measure strains in the beams, SR-4 resistance strain gages were used. Most members had A-5-1 or A-1 gages attached. Two members had AR-1 strain rosettes. A minimum of two strain gages was applied to all beams and on most of these beams strain records of both gages were made simultaneously. Where only two gages were used they were cemented on the beams close to the welds in the top and bottom connections. The location of these gages is recorded in Table 3.

Strains from static tests were recorded on a 6 channel Brush oscillograph and universal amplifiers. Dynamic strains were recorded on one unit of a 6 bank oscilloscope using an immediate developing camera, a Sanborn single channel recording oscillograph and amplifier, or a six channel Brush oscillograph and universal amplifiers. Excitation for the gage recorded on the oscilloscope unit was by a transistorized dynamic bridge amplifier with dynamic null balancing.

Static tests were performed in a 400,000-lb hydraulic universal testing machine. For small beams in low load ranges the load was determined through a 50,000-lb proving ring attached to the upper flange of the beam. All ranges of the testing machine used were calibrated with this proving ring. Strain readings from the oscillographs were calibrated against a wheatstone bridge strain indicator.

Fabrication of Connections

All fillet welds of the beam connection were designed for failure in the weld metal. This required a relatively short length of weld with small throat area.

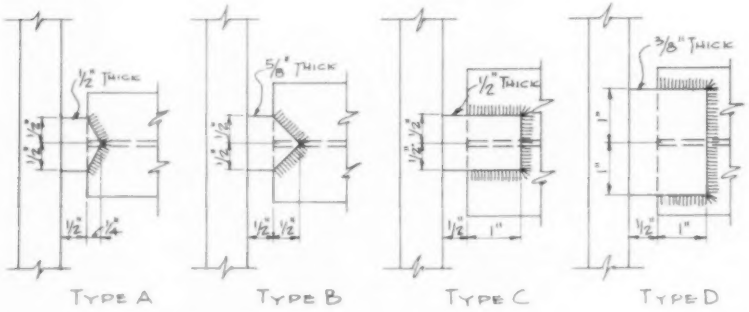


Fig. 3 Top connection details

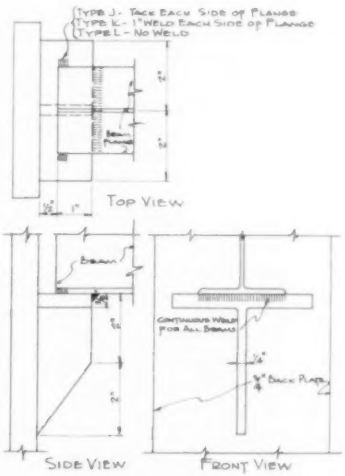

TYPE J - TACK EACH SIDE OF FLANGE
TYPE K - 1" WELD EACH SIDE OF FLANGE
TYPE L - NO WELD
TOP VIEW
BEAM
CONTINUOUS WELD FOR ALL BEAMS
3/4" BACK PLATE
SIDE VIEW
FRONT VIEW

Fig. 4 Bottom connection details

Table 3—Summary of Results of Tests on Junior Beams

Beam designation	Connection weld: Top	Connection weld: Bottom	Loading: Type	Loading: Drop number	Loading: Maximum load or weight (lb)	Loading: Height of drop (in.)	Top Strain gage: Inches from back	Top Strain gage: Maximum strain (in./in.)	Bottom Strain gage: Inches from back	Bottom Strain gage: Maximum strain (in./in.)	Location of failure	Average depth across failure (in.)	Length of failure plane (in.)	Area of failure plane (in.²)	Computed net work in beam at failure (in.#)	Ratio dynamic / static work at failure	Remarks
Series 6–1 through 6–6																	
6–1	A	J	Static		1,650		1 11/16	0.00052	2 1/4	0.00165	Top weld	1/8	1.25	0.16	147		
6–2	A	J	Static		1,600		1 7/8	0.0007	2 1/4	0.0015	Top weld	1/8	1.25	0.16	140		
6–3	A	J	Dynamic	4	86	10	1 11/16	Drop 4 0.00085	3 1/16	Drop 4 0.00108	Top weld	1/8	1.25	0.16	820	5.7	Drops of 6, 7 and 8 in. before failure drop
6–4	A	J	Dynamic	3	86	11	1 11/16	Drop 3 0.00085	2 11/16	Drop 3 0.00120	Top weld	1/8	1.25	0.16	905	6.3	Drops of 9 and 10 in. before failure drop
6–5	A	J	Dynamic	2	86	10 1/2	1 11/16	Drop 2 0.00068	2 7/8	Drop 2 0.00105	Top weld	1/8	1.25	0.16	860	6.0	Drop of 10 in. before failure drop
6–6	A	J	Dynamic	1	86	10 1/2	1 7/8*	Drop 4 0.00105	3 9/16*	Drop 4 0.00105	Top weld	9/64	1.25	0.18	860	6.0	* 6 gages on beam. Figure 10 Drops of 9, 9 & 10 in. before failure drop
Series 8–1 through 8–6																	
8–1	B	J	Static		1,300		2	0.0014	2 1/8	0.00165	Top weld	1/8+	1 3/4+	0.22+	375		
8–2	B	J	Static		1,250		1 7/8	0.005	2 1/4	0.0024	Top weld	1/8+	1 3/4+	0.22+	365		
8–3	B	J	Dynamic	12	86	12					Top weld	3/32	1 3/4	0.16	910	2.5	Loaded 44 in. from back Drops of 4 1/2, 5, 5 1/2, 6, 6 1/2, 7, 7 1/2, 8, 8 1/2, 9, 9 1/2 in. before failure drop
8–4	B	J	Dynamic	10	86	20			2 1/4	0.0014	Top weld	1/8	1 3/4	0.21	1510	4.1	Loaded 44 in. from back Drops of 5, 10, 10 1/2, 11, 11 1/2, 12, 12 1/2, 13 1/2, 15 in. before failure drop
8–5	B	J	Dynamic	10	86	25			2 1/4	Drop 9 0.0017	Top weld	1/8	1 3/4	0.185	1890	5.1	Small crack started 8th drop. Drops of 16, 17, 18, 19, 20, 21, 22, 23 & 24 in. before failure drop
Series 8–1 through 8–6 (continued)																	
8–6	B	J	Dynamic	4	86	20			2 3/8	Drop 3 0.0012	Top weld	1/8	1 3/4	0.24	1510	4.1	No plate under hammer Drops of 18, 18 & 19 in. before failure drop
Series 8–7 through 8–12																	
8–7	B	J	Static		3,000		2	0.0006	2 9/16	0.0012	Top weld	1/8	1 3/4	0.22	190		Loaded two previous times
8–8	B	J	Static		3,000		1 15/16	0.001	2 1/2	0.0012	Top weld	1/8	1 5/8	0.20	190		
8–9	B	J	Dynamic	5	148	11	2	Drop 3 0.00135	2 5/8	Drop 3 0.00135	Top weld	1/8	1 13/16	0.21	1440	7.6	Drops of 7, 8, 9, 10 in. before failure drop
8–10	B	J	Dynamic	4	148	10	2	Drop 3 0.0016	2 1/2	Drop 2 0.0012	Top weld	1/8	1 5/8	0.20	1300	6.9	Drops of 7, 8, 9 in. before failure drop
8–11	B	J	Dynamic	2	148	9	2 1/8	Drop 2 0.0012	2 1/2	Drop 2 0.0010	Top weld	1/8	1 9/16	0.20	1170	6.2	Drop of 8 in. before failure drop
8–12	B	J	Dynamic	4	148	11	2	Drop 3 0.00135	2 1/2	Drop 3 0.00135	Top weld	1/8	1 5/8	0.20	1430	7.5	Drops of 8, 9, 10 in. before failure drop
Series 10–1 through 10–8																	

Table 3—Summary of Results of Tests on Junior Beams (Continued)

Beam designation	Connection weld Top	Connection weld Bottom	Loading Type	Loading Drop number	Loading Maximum load or weight (lb)	Loading Height of drop (in.)	Top strain gage Inches from back	Top strain gage Maximum strain (in./in.)	Bottom strain gage Inches from back	Bottom strain gage Maximum strain (in./in.)	Location of failure	Average depth across failure (in.)	Length of failure plane (in.)	Area of failure plane (in.²)	Computed net work in beam at failure (in.#)	Ratio dynamic / static work at failure	Remarks
10-1	D	K	Static	...	12,900	...					Top weld		4		1600		
10-2	C	L	Static		12,050						Bottom weld	1/8+	2 3/4	0.35+	1400		Slight crack in top weld
10-3	C	J	Static		12,750						Top weld	1/8+	3	0.38+	1580		End plate bent about 3/16 in. from vertical at top
10-4	C	J	Static		11,000						Top weld	1/8+	3	0.38+	1170		
10-5	D	J	Dynamic	2	560	6 15/16					Top weld	1/8+	4	0.50+	3040	2.1	Drop of 2 3/4 in. before failure drop
10-6	C	J	Dynamic	2	560	4					Top weld	1/8+	3	0.38+	1750	1.2	Drop of 3 in. before failure drop
10-7	C	J	Dynamic	2	560	4					Top weld	1/8+	3	0.38+	1750	1.2	Drop of 3 1/2 in. before failure drop
10-8	C	J	Dynamic	2	560	4					Top weld	1/8+	3	0.38+	1750	1.2	Drop of 4 in. before failure drop
										Series 10-9 through 10-14							
10-9	B	J	Static	...	5,600	...	2	0.0014	2 11/16	0.0007	Top weld	1/8−	1 3/4	0.22	325		
10-10	B	J	Static	...	4,950	...	2 3/16	0.0002	2 3/8	0.0012	Top weld	1/8	1 11/16	0.20	255		
10-11	B	J	Dynamic	4	199	12	2 1/8	Drop 3 0.00094	2 1/2	Drop 3 0.00092	Top weld	7/32−	1 3/4	0.36	1860	6.4	AR-1 Strain Rosettes on beam flanges near connection. Lever arm 42-5/8 in. from center of load to back plate. Drop of 9, 10 & 11 in. before failure drop
10-12	B	J	Dynamic	1	199	11	2 3/32	0.00055	2 3/8	0.0012	Top weld	3/32	1 3/4	0.18	1710	5.9	
10-13	B	J	Dynamic	1	199	10	1 15/16	0.00055	2 9/16	0.0010	Top weld	5/32	1 11/16	0.24	1550	5.3	
10-14	B	J	Dynamic	3	199	10	2 5/32		2 3/4	Drop 1 0.00105	Top weld	1/8	1 11/16	0.21	1550	5.3	Drops of 8 and 9 in. before failure drop
										Series 12-1 through 12-6							
21-1	B	J	Static	...	7,400	...	2 1/16	0.001	2 5/8	0.0007	Top weld	1/8	1 3/4	0.22	670		Weld grapey along half of one side
12-2	B	J	Static	...	7,750	...	2 1/8	0.00095	2 3/16	0.00090	Top weld	1/8	1 3/4	0.22	730		
12-3	B	J	Dynamic	3	236	10	2 1/16	Drop 2 0.0012	2 1/2	Drop 2 0.0010	Top weld	5/32	1 3/4	0.28	1540	2.2	Drops of 8, 9 in. before failure drop
12-4	B	J	Dynamic	1	236	8	2	0.00065	2 7/16	0.001	Top weld	1/8+	1 3/4	0.25	1240	1.8	
12-5	B	J	Dynamic	3	236	9	2 1/16	Drop 2 0.001	2 1/2	Drop 2 0.001	Top weld	5/32	1 5/8	0.25	1390	2.0	Drops of 7 and 8 in. before failure drop. Small crack formed first drop
12-6	B	J	Dynamic	1	236	7	2 1/16	0.0007	2 3/8	0.00085	Top weld	9/64	1 5/8	0.23	1080	1.5	

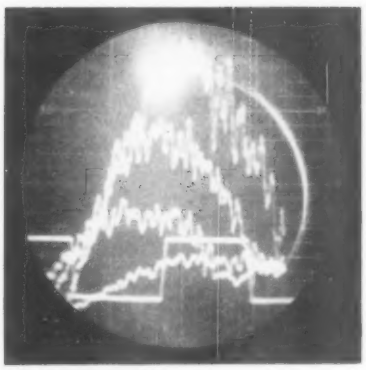


Fig. 5 Photographic record of impact shown on cathode-ray oscilloscope. Curves show strain on top flange of beam near weld. Curve with greatest ordinate is for main drop. Other curves represent successive rebounds of the weight. Square wave gives frequency; in this case, each division represents approximately 1.3 milliseconds. Record for beam 8–3, drop 11

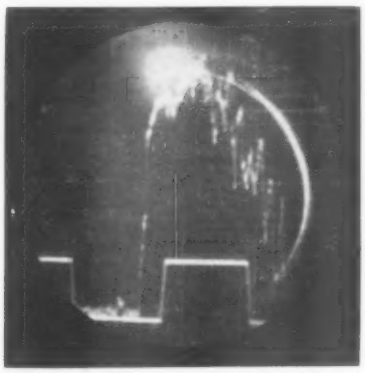


Fig. 6 Sequel to Fig. 5. Record of strain on top flange of beam near weld at instant of failure in the top weld. Time base and scale of ordinates are the same as in Fig. 5. Record for beam 8–3, drop 12

The minimum-size fillet weld possible to control was approximately $^3/_{16}$ths of an inch. V-shaped top-plate connections were used for most of the members since they produced a shorter length of weld than a rectangular plate.

Since the weld was short, great care was required to eliminate a crater at the end of the pass. It was possible on most of the members to completely eliminate a crater but some had slight imperfections particularly at the edge of the beam. As close uniformity of welds as possible was maintained but throat area varied within each series. Series 8–7 through 8–12 were fabricated completely before welding of the top connection was started. All welds in this group were done in sequence so that a uniform amperage could be maintained with the welding machine.

All welding was performed by the same welder using the same welding equipment. This welder is certified by the U. S. Navy for three types of welding including arc weld.

Test Procedure

In general, beams were fabricated in groups of six. Two of each series were subjected to static loading and four to dynamic loading. For the first two series, the static tests were used as a guide to predict the height of drop for failure by dynamic load. This estimated drop was the first made on the beams in this series. Since this drop did not cause failure for any beam, the height of drop was increased in increments until failure occurred. This succession of drops ranged from twelve required to fail the weld to one where the weld failed instantly.

When the cathode-ray oscilloscope was used to record strains, it was adjusted so that the first transient wave was completely recorded on the screen. This was done by triggering the horizontal sweep with the input signal. The input signal resulted from a change in the strain conditions of the SR-4 gage.

Strain records of the impact transients made on the oscilloscope (Figs. 5 and 6) showed that the time required to record the complete loading cycle of the first shock was within the range of the 6 channel recording oscillograph. This unit was thus used for about one half of the work.

The effect of impact unbalanced the bridge in most cases and the recording oscillograph was rebalanced after each drop even though the weld did not fail.

After the welded connection had failed, the weld was broken apart and the cross-sectional area of the failure plane was measured. These failure planes were irregular and the areas listed in Table 3 are approximately within 10% of the exact value. The failure plane varied from horizontal to vertical resulting in varying cross-sectional areas.

Test Results

Effects of Connections

Failure in the top connection under static loading for rectangular plates was progressive and, in general, started from the front fillet weld and proceeded to the side welds. Progressive failure was not evident in the V-shaped connections and no cracking was evident prior to failure.

Several of the rectangular top-connection weld failures had a fracture line close to the horizontal for the front weld and a more vertical fracture line for the side welds. Failures in the V-shaped connections varied between horizontal and vertical but were predominately at about 45° from the horizontal.

The welded connections did not connect to the full width of the flange. This caused large localized strains that dissipated rapidly from the welded connections. This concentration is evident from a study of the strain records since the gages for groups of beams were placed close to but at different locations from the welded connection. In several beams, the flange yielded plastically in the region forward of the weld along the longitudinal center line at the web. A full-width top connection would probably have eliminated this condition although,

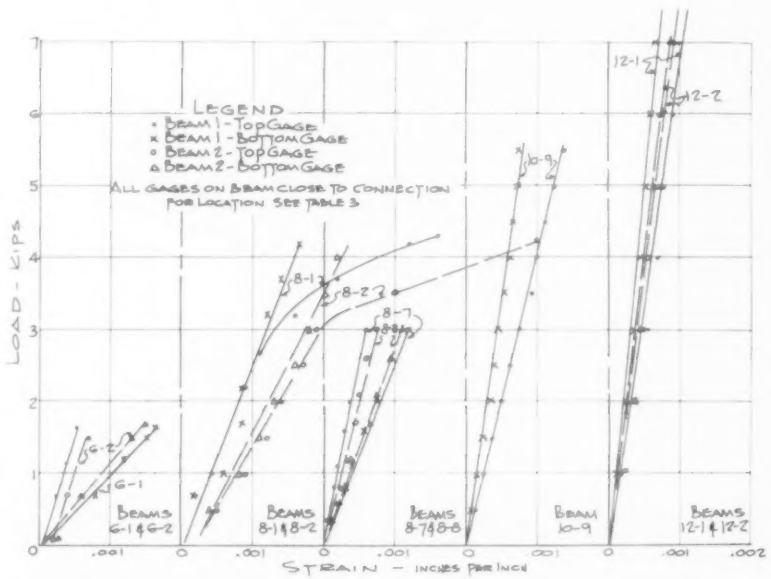


Fig. 7 Static load—strain curve for beams

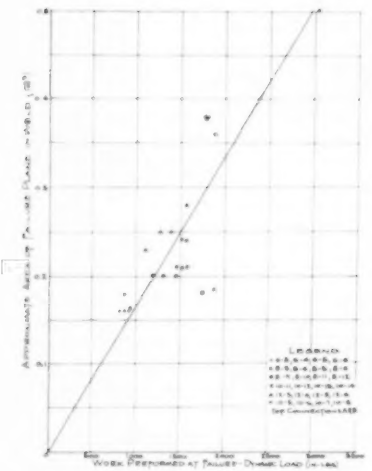


Fig. 8 Relationship between dynamic work producing failure and area of failure plane

in general, higher strains were recorded on the bottom flange close to the support than were noted for the top flange. This bottom connection was welded for the full width of the flange. Tack welds were employed at the corners of the flange connecting to the stiffened seat. It is probable that the stiffness of this connection attracted a greater strain than the more flexible top plate.

Only one member failed in the bottom weld connection through shear. This connection did not have a tack weld at the corners of the beam connecting it to the stiffened seat.

Computations of Strain Energy and Work

Using the static tests, computations were made to determine the total energy absorbed in the beam at the failure of the weld. This was done assuming a linear strain distribution across all sections of the beam, a linear relation between stress and strain, and integrating for the total internal energy absorbed. The total energy absorbed by this beam in bending is $\int_{L_1}^{L_2} M^2 dx / 2EI$. For the cantilever beam, this expression becomes $P^2L^3/6EI$. This expression does not recognize energy losses.

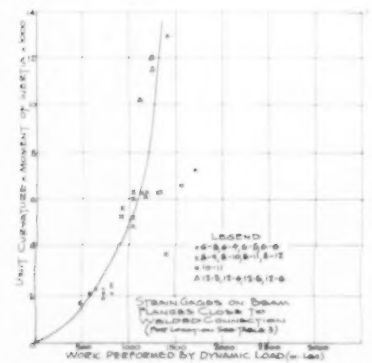


Fig. 9 Relationship between dynamic work not producing failure and maximum curvature. Data from Table 4

The external work resulting from impact is the product of the falling weight and the total drop. This drop is the height from the initial position of the weight to the undeflected beam plus the deflection of the beam under impact. This should equal the internal work performed before the weld cracks. Equating these two expressions $W(h + \Delta) = P^2L^3/6EI$ + major losses + minor losses.

The major loss is the energy absorbed by the movable test frame. This varies from about 5% of the total absorbed in the entire system for tests with 6-in. beams to about 35% of the total for tests of twelve inch beams.

Minor losses include the change in velocity of the falling weight when the beam is struck, deformation in the support columns and concrete base, localized deformation under the hammer, friction between the weight and guides, and air resistance. The first of these losses amounts to a theoretical maximum of 4% for the 6-in. beams, 6% for the 8-in. beams, 3% for the 10-in. beams, and 5% for the 12-in. beams.

In addition, shear energy is excluded from the expression. This strain energy is small and is not an important consideration for most beams.

Considering losses, the energy required to fail the weld under dynamic loading is from 1.2 to 7.6 that required by static loading. Some variation can also be expected because of the nonuniformity in cross-sectional area of small welds.

Figure 8 relates the total external work computed at failure of the weld to the cross-sectional area of the plane of failure. A straight-line relationship appears to exist for these data. Some relationship is shown between the work performed by dynamic load and the product of the unit curvature and the moment of inertia. This angle was computed by summing the strains in the top and bottom flanges close to weld and dividing by the depth. Some of the results of this study are shown in Table 4 and Fig. 9.

The cross-sectional area of the welds used in these tests is too small to use for conclusive interpretation. Before definite conclusions can be made, it is advisable to test many large-scale members and connections and interpret these. It is anticipated that less deviation between static and dynamic work will result from tests on larger beams.

After striking the beam, the weight bounded and continued to strike again until all energy was expended. In many cases when failure did not occur, the beam reversed strain conditions after the load was off the member. Top gages show locked-in compressive strains, bottom gages do not show this phenomena. When the weld failed,

Table 4—Beam Curvature Resulting from Effect of Dynamic Work. Curvature Close to Welded Connection

Beam designation	*Dropped weight (lb)*	*Drop (in.)*	*Computed net work in beam (in.-lb)*	*Strain (in./in.)*		*Curvature radians per in. C*	*Curvature × moment of inertia × 1000*
				Top gage	*Bottom gage*		
6-3	86	6	490	0.00054	0.00093	0.00024	1.75
		7	570	0.00074	0.0010	0.00029	2.11
		8	650	0.00085	0.00105	0.00032	2.33
6-4	86	9	740	0.0006	0.00115	0.00029	2.11
		10	820	0.00084	0.0012	0.00034	2.48
6-5	86	10	820	0.00065	0.00105	0.00028	2.04
6-6	86	9	740	0.00065	0.00092	0.00026	1.90
		9	740	0.00085	0.0010	0.00031	2.26
		10	820	0.0009	0.00105	0.00033	2.41
8-9	148	7	910	0.0011	0.0011	0.00028	5.25
		8	1040	0.00135	0.0012	0.00032	6.0
		9	1170	0.00135	0.00135	0.00034	6.35
		10	1300	0.00135	0.00135	0.00034	6.35
8-10	148	7	910	0.00125	0.00115	0.0003	5.60
		8	1040	0.0015	0.0012	0.00034	6.35
		9	1170	0.0016	0.001	0.00033	6.2
8-11	148	8	1040	0.001	0.00105	0.00026	4.85
8-12	148	8	1040	0.00105	0.00115	0.00028	5.25
		9	1170	0.00135	0.00125	0.00033	6.18
		10	1300	0.00135	0.00135	0.00034	6.35
10-11	199	9	1400	0.0006	0.00036	0.000096	3.74
		10	1550	0.00088	0.00085	0.00017	6.63
		11	1710	0.00094	0.00092	0.000186	7.25
12-3	236	8	1240	0.00095	0.00095	0.00016	11.5
		9	1400	0.00120	0.0010	0.00018	13.0
12-5	236	7	1080	0.0008	0.0009	0.000142	10.20
		8	1240	0.001	0.001	0.000167	12.00

tensile residual stresses were generally left in the top flange of the beam close to the weld.

The Transmission of Dynamic Strain Through a Beam

The time required for the impact stress wave to be transmitted to different locations of the beam was determined by placing strain gages at these locations and recording the strain pattern of each to a common time base. The results of one of these tests are shown in Fig. 10. The time lag from the beginning of the strain wave at locations close to the load does not exceed the beginning of the strain at more remote locations by more than one millisecond. The times of peak intensity for each strain, however, lag between different locations by as much as six milliseconds.

Locations closer to the load show a flat sustained peak of strain. Gages farther from the load have the sharpest peaks. In all locations recorded the strain picked up slowly and then increased rapidly. The total time required to reach a peak was from approximately 15 milliseconds to 22 milliseconds, the more rapid rates being at locations more remote from the load. The total time from beginning of strain to complete decay was about 32 milliseconds.

The time-strain curve for a subsequent drop causing failure is shown in Fig. 11. A marked difference is noted between these two curves.

Converting the strains of gages 1, 2 and 3 of Fig. 11 to stress through the static modulus of elasticity, and the stresses to static load through the straight line theory gives values of load almost exactly equal to the static load required to fail a similar beam in a universal testing machine. Gages 3 and 6 in regions of high stress concentrations cannot be directly extrapolated.

Impact Fatigue

There is no obvious relationship between the stress histories of members that failed under the first impact force or those that failed after a dozen drops. It is probable, however, that this is a significant factor in the resistance of welds and impact fatigue-stress curves should be determined. Fatigue load is increased in each case because of the rebound that occurred for each drop in beams that did not fail. Damping was rapid, however.

Three series of beams were tested using the same connections and welds. These included series 8–7 through 8–12, 10–9 through 10–14, and 12–1 through 12–6. This was done to provide additional information on the effect of the size of member on the work energy at failure and to obtain representative failure conditions under various stress intensities in the beams. Results from

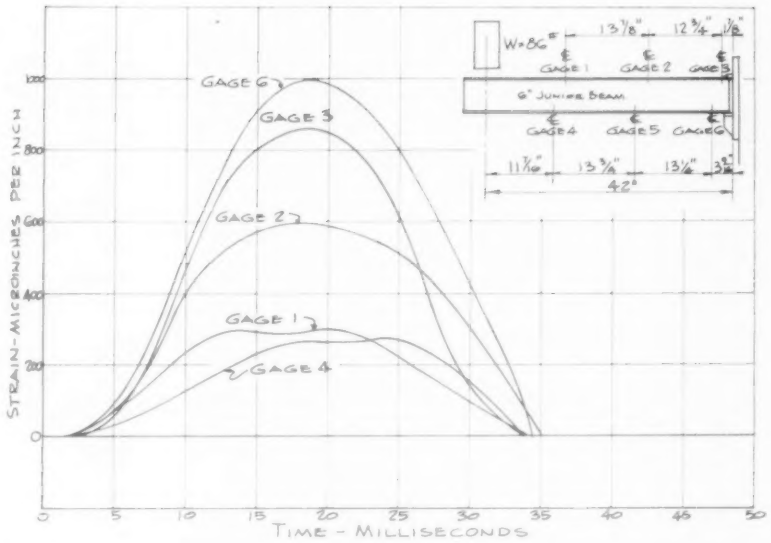


Fig. 10 Time-strain curves of beam 6-6 for drop 2 of 9 in. Failure did not occur

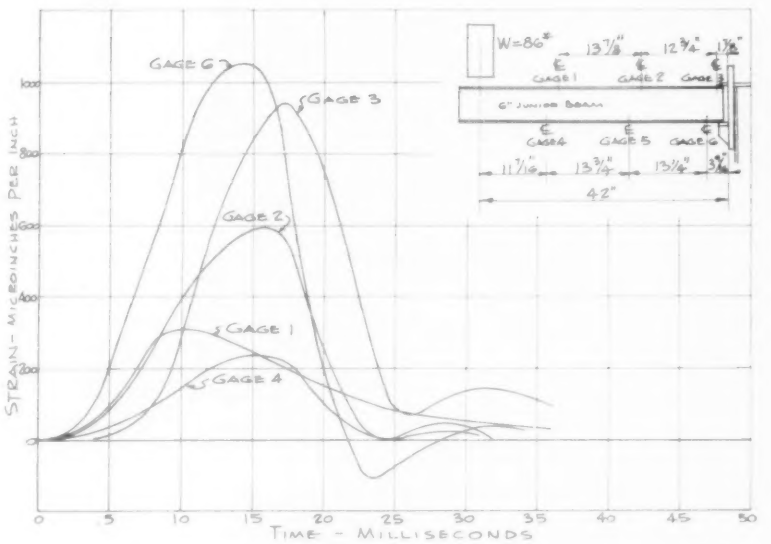


Fig. 11 Time-strain curves of beam 6-6 for drop 4 of $10\frac{1}{2}$ in. Weld failed

these groups were relatively consistent but it was also possible to include with them the 6–1 through 6–6 series for interpretation.

Conclusions

The program reported in this paper is limited in scope, and conclusions should not be extrapolated beyond the extent of the members that have been tested.

In the light of the results in this program, it is concluded that:

1. For the members tested, the theory as used has a factor of safety from 1.2 to 7.6.

2. The ratio of dynamic to static work at failure was (with the exception of one series) lower for larger members.

3. V-shaped connections failed without noticeable starting cracks even under static loading, while a rectangular shaped connection cracked at the front face first and progressed to the sides.

4. The concentrated stress conditions in the beam in the vicinity of the weld do not have a detrimental effect on the strength of the connection but may cause excessive deflections of the beam.

5. Maximum strain conditions many times occur prior to the impact, causing failure.

Recommendations

It is suggested that before conclusive results are obtained it will be necessary to:

1. Perform tests on larger structural

members using large connections and welds. These should be performed on a larger number of beams in each group.

2. Compare tests on cantilever beams with tests on connections of beams supported and connected at both ends.

3. Determine the characteristics of five or six different types of welded connections.

4. Determine the effect of the impact-fatigue history upon the failure of the connection.

5. Determine the effect of plasticity of the beam upon impact failures.

6. Compare the time-strain relationships for small- and large-size members and for members with different end conditions.

7. Compare the effect of various combinations of weight and height of drop upon connections.

8. Consider these effects in full structural frames.

Acknowledgment

Beams for this investigation were furnished by the Jones and Laughlin Steel Co. All other material and all labor for the fabrication of the beams used in this test were provided by the University of Delaware.

HEAT OUTPUT, PENETRATION, AND ARC FORCE OF WELDING ELECTRODES

BY F. ERDMANN-JESNITZER AND K. PRIMKE

The heat output of three types of steel electrodes and a bronze electrode was determined by measuring the temperature rise of a bar on which they were deposited. At a given current the least heat was produced by the bronze electrode. Wash-coated steel electrodes (large globular transfer) also produced relatively little heat, with medium heavy covered electrodes producing larger quantities. The medium heavy covered electrodes included an austenitic stainless-steel electrode (Croni 18-8), a low-hydrogen type and a 6012 type, all having medium globular transfer. The maximum heat was delivered to the work by 6020 and deep penetration types. When the heat outputs were compared on the basis of arc energy (amperes × volts × time), the results for all electrodes fell close to the same curve. The results of distortion measurements followed the same pattern as the heat outputs.

Abstract by **Gerard E. Claussen** of "Beitrag Zur Warmewirkung Von Elektroden, Zum Tiefbrandeffekt und Zur Messung Mechanischer Krafte im Schweisslichtbogen," published in *Schweisstechnik* (Berlin), **6**, 321-327, 353-361 (1956). A paper from the Institute of Metallurgy and Materials Testing of the Freiberg Mining Academy.

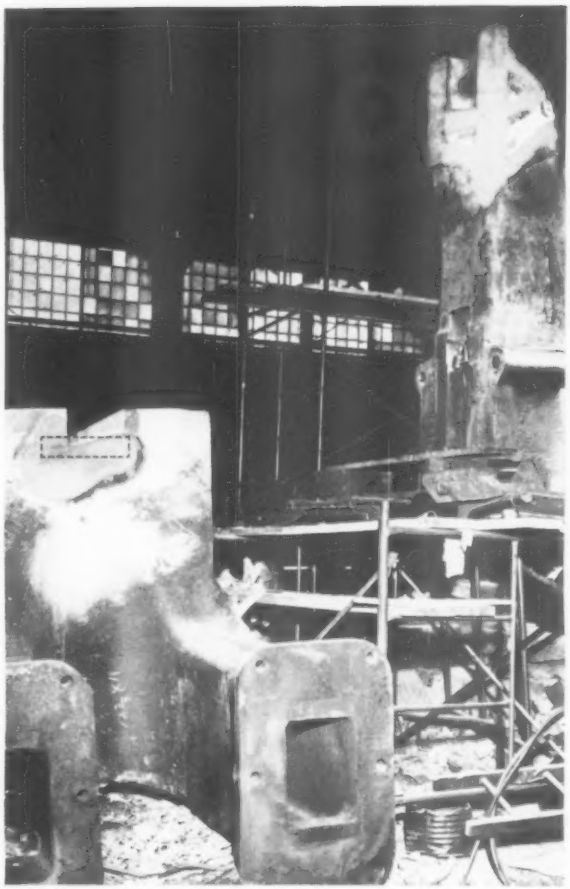
Dr. Claussen is associated with the Development Laboratories, Linde Co., Newark, N. J.

An unsuccessful attempt was made to explain the deep penetration obtainable with deep penetration electrodes. A commercial deep penetration electrode, $^5/_{32}$ in. diam, 17.7 in. long was tested for penetration and heat output in three conditions: (*a*) dried to constant weight at 284° F, (*b*) normal moisture content, which was 0.6 (+0.01, −0.06) g per 17.7 in. of electrodes and (*c*) humidified 44 hr at 100% humidity to bring the moisture content to 2.0 g in 17.7 in. Dipping in water was not resorted to, because dextrine dissolved from the coating. Penetration was measured with and without a gap of 0.08 in. between the plates. The welding current varied from 120 to 250 amp in different tests. In all tests the humidified electrodes produced 0.04 in. deeper penetration than the normal and dried electrodes. At a given current the heat output was higher for the humidified electrode. However, when the results were compared at the same power level (amperes × volts) the dried electrode had the highest heat output, the humidified electrode the lowest.

One typical deep penetration electrode had a coating containing 34% wood flour, 37% pigment TiO_2, 8.1% ferromanganese (90% low carbon grade), 12.1% mica, 8.8% magnesite. To 5000 cc of wood flour, 800 cc of water was added to bring it to the gel state.

The arc force exerted by covered electrodes was measured by suspending the electrode horizontally as a pendulum. The electrode was attached to a block floating in mercury. At a given current dried electrodes exerted about 50% less force than normal electrodes. Humidified electrodes exerted even higher force. For example at 250 amp the force pushing the electrode away from the plate was 0.4 g for the dried electrode, 0.8 g for the normal and 1.2 g for the humidified electrode. Compared at the same power level the normal and humidified electrodes exerted the same force, the dried electrode being lower. The results made it impossible to decide whether deep penetration was due to suddenly dissociated gases, particularly water, in the coating, or to electrodynamic forces or to expansion of gas from the coating.

The arc force exerted by a bare electrode (230 amp, 15 v) was found to be attractive. Perhaps the transferring drop pulled the electrode toward the plate during short circuit. No arc force was detected with low-hydrogen electrodes (300 amp, 29 v) nor with a carbon electrode $^5/_{32}$ in. diam, 180 amp, 32 v.



Rear view of dismantled hammer. Right-hand frame was lowered to weld the slab of steel—4" x 16" x 72"—indicated by dotted line—into the guidespacket section. Left-hand frame was welded in vertical position.

The repaired steam hammer back in operation two months after the breakdown. Approximately 1850 pounds of Tobin Bronze Welding Rod were used. Color indicates location of welds visible from the front.

This mammoth repair saved $115,000 ... and six months' production time

A 16,000-pound, double-frame steam forging hammer in the plant of a leading tool steel manufacturer broke down early last November. The top portions of both side frames were broken into about 5 pieces each, and several pieces of flange near the steam cylinder were missing. The bed plates were badly damaged. There were between 700 and 800 linear inches of fractures in sections with wall thicknesses of 3 to 5 inches. To repair the hammer seemed a colossal undertaking—but it would take 8 months to get a new hammer into production at a cost of about $140,000.

Maintenance Engineering Corporation, Pittsburgh, Pa., which specializes in the rehabilitation of large industrial equipment, was called in to see if repairs were feasible. After careful study of the damage and an analysis of possible repair methods, their engineers chose braze-welding with Tobin Bronze Welding Rod. They estimated the hammer could be returned to service at a cost of approximately $25,000 or less than one-fifth the cost of a new hammer.

After dismantling and preparation, welding was under way by November 25. It took eight working days using 10 weldors on a 12-hour daily shift. The machine was back in production January 1—two months after it broke down—and is still going strong.

Maintenance Engineering Corp. uses Tobin Bronze Welding Rod for all welding repairs because the welds have good strength and the molten weld metal has excellent flowing properties. The latter enables them to control the weld puddle more effectively in vertical welds and other difficult positions.

There are Anaconda Welding Rods for a wide variety of repair and production applications. They are sold by distributors of welding equipment everywhere. For help in selecting the exact rod to fit your need, see your distributor or write: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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